A REVIEW OF MINE MAINTENANCE IN CANADA

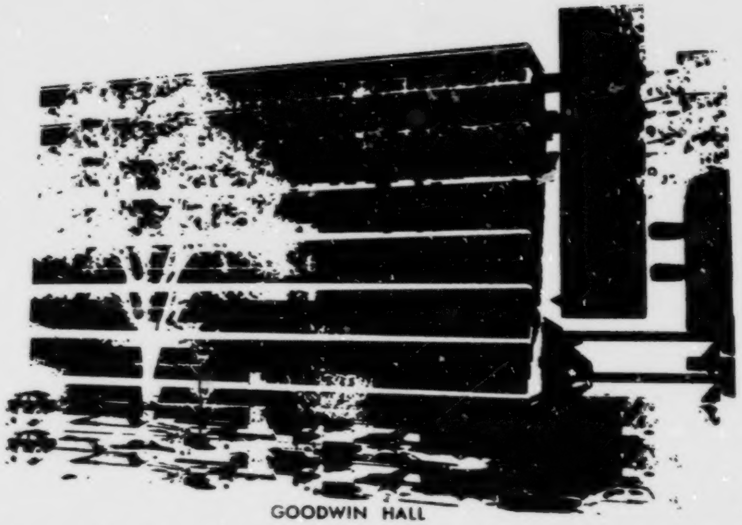
PREPARED FOR CANADA CENTRE FOR MINERAL AND ENERGY TECHNOLOGY

(CANMET)

UNDER

DSS CONTRACT NO. 20 SU 23440-3-9094

NOVEMBER 1983



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A BIBLIOGRAPHY OF
MINE MAINTENANCE SYSTEMS

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In account with the requirements of
D.S.S. OSU.23440-3-9094
Contract Serial No. ISU 83-00131

29 August 1983

47 pp

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MICROMEDIA

MAINTENANCE MANAGEMENT - A BIBLIOGRAPHY

1. Introduction

Proper maintenance management has been emphasized over the past two decades due to increased complexity of systems, increased quality requirements and rising costs of material and labour. The two old concepts of maintenance: loving care (the reliability of the equipment is directly proportional to the frequency of maintenance), and emergency replacement (operate equipment until it breaks down) are no longer applicable. Both methods lead to improper maintenance, excessive breakdowns and high costs. Since the mid 1960's extensive research has been going on in the fields of management science, industrial engineering, systems analysis and operational research and developments in these fields have contributed greatly to maintenance management. Various techniques have evolved to the point where they have become useful in solving many of the maintenance manager's traditional problems.

In today's mining industry better maintenance management certainly is needed. Plant and equipment are now much larger, more automated and much more expensive to own than ever before. The costs associated with maintenance and equipment unavailability are now so high that maintenance management has become a critical factor in company profitability. Unfortunately, however, with the exception of a few large companies, there is very little evidence that the systems and techniques available are being used to assist in the management of maintenance. Though there is a strong desire to improve existing systems, it appears that very little is known as to the whereabouts of the relevant literature which can provide the information and guidance in this regard.

This bibliography was prepared to provide a solution to the above problem. It presents a comprehensive listing of references, covering the full spectrum of the subject. References are listed in alphabetical order according to author and each is accompanied by an abstract of the article of book concerned. References, as shown in Table I, are classified under three main headings:

Conceptual Features;
Application;
Analytical Techniques.

Sub-grouping is employed, where necessary, to improve clarity and facilitate use.

In addition, as shown in Table II, references covering the area of Application are further classified according to industry to assist in funding different relevant material and to facilitate the search for details of procedure and application. Some references appear more than once in both Tables I and II because they cover two or more topics.

This bibliography should prove useful to mine managers, maintenance staff and others in the field and should serve as the starting point for the improvement of maintenance management in the mining industry.

2. Classification of References

The following is a brief explanation of the classification system used.

2.1 Conceptual Features

A maintenance management program should ensure optimum plant and equipment performance for the lowest practical financial outlay and should provide for the supply of adequate management data to demonstrate achievement of these aims. In order to achieve these objectives, certain fundamental features are essential to a program. These include:

The Organization (department) involved
Systems and procedures
Strategic Maintenance Plan
Planning and Scheduling procedures
Information System

In addition there should be certain supporting features which include: attitude to maintenance; maintenance objectives; maintenance policies; total life-cycle maintenance; maintenance annual report; maintenance management manual. These features should provide support to a program by creating the right environment for its development and operation.

The implementation of a program which eventually includes all the above features, results in a loop of action and provides the information feedback that is so essential to the management of maintenance.

References in this classification grouping are subgrouped according to the five essential features and the support features. (see Table I)

2.2 Application

The fundamental and supporting features mentioned above apply to the maintenance management program, whatever the application. However, depending on the area of application; local circumstances will differ and the degree of importance and extent of application of each feature will vary significantly.

For any mining venture, certain specific considerations are necessary prior to developing a maintenance program. These include, company policy, nature of operation (surface or underground), geographic location (accessibility), size of operation and type of equipment. These and other relevant factors must be considered so that the program is tailored to meet the needs of the individual operation. Special consideration should also be given to computer application since, for large operations, systems can become swamped with paperwork and control is almost impossible.

References in this grouping cover a wide range of industrial applications including, manufacturing, chemical, military, airline, mining and processing. (See Tables I and II)

2.3 Analytical Techniques

Traditionally, maintenance managers in industry are expected to cope with maintenance problems without seeking to operate in an optimal manner. For example, many schemes are put into operation with very little, if any, quantitative assessment of the problems involved; decisions are based purely on subjective judgement.

The primary purpose of analytical techniques, such as reliability statistics and mathematical modelling is to assist managers in decision-making by using known facts more effectively, by making quantitative assessment and by reducing reliance on subjective judgement. References in this grouping cover such techniques as work measurement, work sampling, reliability (failure) statistics and mathematical modelling. (See Table I)

TABLE I GENERAL CLASSIFICATION OF REFERENCES

GROUPING	REFERENCE NO.
CONCEPTUAL FEATURES:	
ORGANIZATION (structure, staffing, training, facilities)	12, 17, 21, 23, 27, 28, 46, 49, 56, 58, 61, 67, 72, 74, 81, 87, 98
SYSTEMS & PROCEDURES (paperwork, stores, standards)	4, 9, 16, 19, 21, 23, 24, 29, 39, 52, 58, 62, 67, 69, 75, 81
MAINTENANCE PLAN (routine, preventive, corrective actions)	3, 4, 7, 8, 19, 21, 23, 31, 32, 55, 56, 58, 67, 70, 77, 80, 81, 85, 88, 93
PLANNING & SCHEDULING	12, 16, 23, 24, 33, 36, 44, 58, 67, 79, 81, 90, 99, 101
INFORMATION SYSTEM (cost control, recording, reporting)	12, 14, 15, 16, 19, 21, 22, 23, 34, 35, 37, 38, 40, 41, 45, 56, 60, 64, 65, 66, 67, 70, 81, 103, 104
SUPPORTING FEATURES (attitude, objectives, policies, etc.)	3, 7, 11, 14, 18, 49, 63, 67, 76, 81

APPLICATION:

GENERAL (all industries except mining)	2, 6, 8, 10, 13, 18, 20, 24, 26, 49, 53, 72, 86, 96
MINING & PROCESSING	5, 7, 9, 15, 17, 19, 27, 28, 32, 36, 43, 44, 50, 51, 54, 59, 64, 65, 70, 71, 72, 74, 79, 82, 84, 91, 93, 94, 97, 100, 102
COMPUTER	5, 8, 20, 25, 30, 41, 42, 45, 50, 53, 67, 68, 73, 78, 83, 84, 92, 93, 94, 97, 100, 102

ANALYTICAL TECHNIQUES:

WORK STUDY (work measurement, work sampling)	1, 29, 62, 69
OPERATIONS RESEARCH (failure statistics, modelling)	4, 6, 10, 31, 47, 48, 52, 86, 89, 95

TABLE II

CLASSIFICATION OF REFERENCES BY INDUSTRIAL APPLICATION

AIRLINE	2, 18
CHEMICAL PROCESSING	26
ENERGY	20, 30, 80, 83, 96
MANUFACTURING	6, 8, 24, 45, 53, 72
MILITARY	10, 13, 49, 86
MINING	5, 7, 9, 15, 17, 19, 27, 28, 32, 36, 43, 44, 50, 51, 54, 59, 64, 65, 70, 71, 72, 74, 79, 82, 84, 91, 93, 94, 97, 100, 102

REFERENCES

[1] ARNOLD, T.L., "Better Way to Use Work Sampling to Measure Maintenance Labour Productivity", Engineering Conference Proceedings, Technical Association Pulp Paper Industry, Book 3, Washington, D.C., Sept. 1980; pp421-426.
The paper is based on a project aimed at finding better ways to measure maintenance labour productivity. In this paper, the author describes the need for measurement in a maintenance improvement program and the pros and cons of using work sampling as a measurement tool. Some suggestions for overcoming the disadvantages of work sampling are made.

[2] AUBIN, B., "Effective Management of In-Service Deficiencies", SAE Preprint N760515, Meeting of May 18-20 1976; 13p.
This paper presents a broad description of the management program used by Air Canada in ensuring "in-service deficiencies" do not jeopardize operations. The review of the procedures and the rationale of the management program is based on objective, perspective, approach, results and future plans.

[3] BALDIN, A.E., "Condition-based Maintenance: A Powerful Tool For Modern Plant Management", Terotechnica, V1, 1979; pp119-129.

The influence of maintenance and related costs on the utilization of fixed assets, in industrial plants, is examined and different maintenance policies are compared. The fundamentals of condition-based maintenance are outlined and its economics and other advantages described. The paper sums up the state of the art and experience gained in maintenance management since the sixties.

[4] BALDIN, A.E., "Global Approach To Plant Maintenance", American Institute Of Plant Engineering, Plant Engineering Conference Proceedings, Montreal, Que., June 1976; 28p.

Critical points in plant maintenance are singled out through cost plus performance analysis. The selection of optimal maintenance policies for improving plant availability is examined, emphasizing the advantage of condition-based maintenance. The importance of an information system is pointed out and plant experiences are reviewed.

[5] BARLOW, J., "Coal Mines Utilizing Computers In Maintenance Management", Australian Coal Miner; 4,(2), 1982; pp44-46.

The use of computerized maintenance management systems in coal mining is described, particularly their applications to such areas as work order generation, stores control, preventive maintenance and information feedback.

[6] BARNETT, K.W. and BLUNDELL, J.K., "Trade Demarcation In Maintenance: Determination of Optimum Crew Sizes By The Monte Carlo Simulation Technique",

Terotechnica, V2, N2, May 1981; pp147-155.
Monte Carlo Simulation is an important technique in maintenance management. In this paper the technique has been used to optimize the maintenance crew size in a small electronics department. The objective of the exercise was to minimize the likely total costs incurred by the department, balancing the costs of machine downtime against the salaries of the repairmen.

[7] BARRIQUAND, E. and STRUNSKI, M., "Organization Of General Services For A Mining Complex", Industrial Miner, Tech.(10); Dec. 1981; pp763-771.
The article defines the general services required by a mining complex and show that these increase the more remote the location of the mine. The basic constituents of these general services are examined; in addition, procedures for preventive maintenance and aspects of maintenance policy are outlined and some operating examples are presented.

[8] BARTON, W.D., "Aspects Of The Use Of Computers in Maintenance Management: Application Of Computers To Preventive Maintenance Scheduling", Terotechnica, V1, N3, March 1980; pp187-196.
This paper describes a computerized system for the scheduling of preventive maintenance activities within a manufacturing organization. The system was applied to a relatively small maintenance operation and for economic reasons was combined with a manual scheduling system to provide the final output. Aspects covered include operation of system, input data, reports generated and uses of output information.

[9] BEVERIDGE, T.S., "Material Management Means Dollars", Coal Age, April 1981; pp137-145.

Highly mechanized, capital intensive mining operations are often impaired by supply deficiencies that waste resources and contribute to equipment downtime, poor productivity and higher operating costs. This article describes how different supply systems can be integrated into a unified material management system that will reduce costs and boost maintenance productivity.

[10] BISHOP, L.L., "Utilization of Army Aviation Experience via RAMMIT", (Reliability and Maintainability Management Improvement Techniques), Proclaimation of 9th Reliability and Maintainability Conference, Detroit, Mich., V9, July 1970, Paper 700589; pp149-159.

RAMMIT is a system designed to process maintenance data and other data relevant to the operations and support of Army aircraft. Omissions and errors in reported aircraft data were studied extensively and it was determined that, if the data were properly processed, useful and reliable information could be provided. This article describes some of the methods used to identify these omissions and errors and shows how data obtained can be used to assist in the assessment of components' characteristics.

[11] BLANCHARD, B.S., "Total Maintenance Management", Terotechnica, V2, N2, May 1981; pp139-145.

Total maintenance management, as presented in this paper, covers those activities required throughout the life cycle of plant or equipment, to ensure that maintenance requirements are optimized. Essentially, the paper examines the concept of total maintenance management, its requirements and its function as a support feature of the maintenance management program.

[12] BLEUEL, W.H., "Maintenance is Not An Expense - It Is A New Source of Profit", Plant Engineering, V35, N25, Dec. 1981; pp75-78.
This article discusses various considerations and analyses aimed at cost reduction and improving maintenance economics. Aspects covered include determining the total cost of ownership, minimizing maintenance costs, direct and implied expenses, cost of ownership analysis and two case studies.

[13] BOGDAN, W.R., "Software Maintenance Management Process", Navy Air Development Center, Pennsylvania, Code 504, July 1980; pp1-9.
This paper discusses the management concepts utilized in developing a maintenance capability to support fleet tactical software. This discussion includes the kind of management planning that is essential to fleet software maintenance, the design factors that will reduce maintenance costs, organizational structure for work accomplishment and the estimating procedures for determining maintenance cost.

[14] BRANDOLESE, A. and TURCO, F., "Economic Life of Industrial Equipment and Maintenance Policy: Two Aspects of a Single Problem", Terotechnica, V1, N4, July 1980; pp271-284.
This paper focuses on the problem of simultaneous

optimization of maintenance and replacement policies for productive equipment in the presence of technological change and demand trend. Specifically, it deals with maintenance policies and their corresponding costs and how they can be used to determine economic life and equipment capacity.

[15] BROUWER, J., "Maintenance Management Programs with EDP for improved Performance and Control", C.I.M. Bulletin, July 1974; pp85-97.
Work programs were implemented into a mine maintenance department, which made use of computer programs for data collection and performance information feedback. This article describes the development, implementation and operation of the work programs.

[16] BRYSON, G., "Engineering Maintenance Management", Coke Oven Managers Association, 1978; pp197-208.
The problems facing maintenance engineers are discussed. Subject areas include, maintenance engineering, cost control, material supply, stores control, planning and scheduling, performance measurement and control. Possible solutions to some of the problems are also included.

[17] BUCKLAND, G.R., "Modular Training for Production and Maintenance Workers at Falconbridge Nickel," C.I.M. Bulletin, Dec. 1975; pp76-81.
Modular training combines formal on-the-job training and classroom instructions. The approach requires that each job be broken down into various individual tasks, or elements of work. This article gives some details of the development of this method of training at Falconbridge Nickel

Mines Limited.

[18] BYRNE, J.G., "An Integrated Equipment Management Program", Society of Mining Engineers, West Metal Tool Conference Technical Paper, V70, March 1970; 22p.

In the management of resources, the normal sequence of problem definition, planning, economic selection and efficient utilization with adequate feedback, provides management with a unified approach to analytical study and decision making. This systematic analysis of a total activity is termed the Life Cycle Concept. In this article the phases and characteristics of the Life Cycle Concept are analyzed.

[19] CAMPBELL, C.A., "Maintenance Control at Algoma's MacLeod Mine", C.I.M. Bulletin, Dec. 1973; pp95103.

The steps taken to develop and implement a maintenance control system, with standards, are outlined. The work order system, standards application, classification of work and preventive maintenance procedures are discussed. Information in maintenance records and control reports and reasons for reporting are discussed. The benefits resulting from the program are reviewed.

[20] CHAVEZ, G., "Managing and Controlling Maintenance", Power, V124, N6, June 1980; pp108-111.

A well-planned maintenance management program can bring organized yet flexible scheduling, improved productivity and a ready-access data bank. This article describes a computerized work order scheduling system - trademarked WOSS, developed

for a nuclear power plant. Points discussed include the design of WOSS, data base used and management tools produced by the system.

[21] CLAIRE, F.V., "Evaluating Maintenance Operations", Plant Engineering, V31, N12, June 1977; pp181-184. The first step in evaluating maintenance effectiveness is a detailed analysis of the overall operation so problems can be identified. This article, the first of two, presents a review of the seven elements to be analyzed: organization, system and procedures, labour performance, facilities and equipment, stores operations, maintenance strategy and information system.

[22] CLAIRE, F.V., "Evaluating Maintenance Operations", Plant Engineering, V31, N13, June 1977; pp125-128. This is the second of the two articles on evaluating maintenance effectiveness. This article describes, in some detail, methods that can be used for conducting the analysis of the seven elements reviewed in article one.

[23] CORDER, A.S., "Maintenance Management Techniques", McGraw-Hill, New York, N.Y. 1976. An examination of some of the techniques employed in the management of maintenance in the manufacturing industry. Subjects covered include: types of organization for maintenance departments, setting up of maintenance services, work programs, developing maintenance strategies with an emphasis on preventive work, developing maintenance standards, measuring performance, planning and scheduling and information control and feedback.

[24] DAVIS, J.H., "Maintenance scheduling System", Industrial Engineering, V7, N5, May 1975; pp40-43.
This article presents the basic operating procedures of a maintenance scheduling system that was designed and implemented in a medium-sized rubber company; in particular, the mechanics of the system, method of operation, and roles of various maintenance personnel. The author also reviews the role of maintenance standards and its importance to maintenance scheduling.

[25] DONNELLY, K., "Computers for Plant Equipment Maintenance - A New Direction", C.I.M. Bulletin, Feb. 1976; pp56-63.
Until recently, because of the lack of standards of measurement and the availability of only a "batch" approach, maintenance control has resisted computer application. Four recent developments have helped to overcome these two problems - visual display terminals, the data data-base communications system, the display management system and the design of an on-line maintenance system. This paper describes these developments and how they can be used to develop an operational maintenance system. Specific reference is made to the processing industry.

[26] EDWARDS, J.D., "Management of the Chemical Plant Maintenance Function", The Chemical Engineer (London), N356 May 1980; pp316-318.
This paper traces the development of management of the maintenance function in the U.K. chemical industry. The author examines traditional pracitices and compares them with present needs and the current situation.

[27] FARMER, W.T., "The Establishment and Development of Central Workshops", Colliery Guardian, Jan. 1972; pp58-65.

This article outlines the development of central workshops in the U.K. coal industry during their first twenty-five years of operation. A review is made of the organization, manpower, facilities and management. Areas in need of change are highlighted.

[28] FINLEY, H.F., "Maintenance Management for Today's High Technology Plants", Hydrocarbon Process, V57, N1, Jan. 1978; pp101-105.

More complex equipment is entering plants today more than ever before. Management must keep it running economically. How can management cope with the requirements of higher technologies? This paper outlines some changes including organizational, technical and administrative changes, that are necessary to meet the new requirements.

[29] FRANCISCO, F. and NIEBEL, B., "Universal Maintenance Standard", Industial Engineering, V8, N2, Feb. 1976; pp26-29.

Indirect labour standards, developed from a universal maintenance standard system, can be reliable and sufficiently accurate - and relatively inexpensive to develop. This paper describes the principles behind the development of the universal maintenance standard system and explains how it can be used to establish a "standards program" for any maintenance situation.

[30] GARRICK, B., JOHN, P. and HAROLD, F., "Maintenance

Management in the Electric Utility Industry", Changing Energy Use Futures, 2nd International Conference on Energy Use Management, Los Angeles, CA., Oct. 22-26 1979; pp1648-1655. Published by Pergamon Press, N.Y.
This paper discusses the major elements of a plant availability program which can achieve improvements in plant productivity. Also discussed is a computer-based maintenance management system designed for use by a Nuclear generating station. It is claimed that the system described can be applied to many industies.

[31] GERTSBAKH, T.B., "Models of Preventive Maintenance", Elseviers-North Holland Co., New York, N.Y., 1977.
Statistical analysis and mathematical modelling are used to develop a number of models for preventive maintenance. The developed models represent different maintenance policies and reference is made as to what particular maintenance situation each applies.

[32] GRAY, E.W., "Planned Maintenance and Workshop Control on the Gold Mines", 7th Commonwealth Mining - Metallurgy Congress, South Africa, 1961; 33p.
The typical schemes used for achieving adequate control in workshops and for scheduling maintenance of mining equipment are detailed. The extent to which such schemes are used in the South African gold mining industry and the benefits reported are assessed.

[33] GROTHUS, H., "Systematic Approach to Maintenance Planning", Plant Engineering, V32, N8, April 1978; pp133-136.

A substantial percentage of breakdowns are primarily because defects are inadequately controlled. Even when deterioration is normal, defects often cause breakdown because they are not detected in time. This article explains how a technique called "defect analysis" can be used to develop a systematic approach to maintenance planning. The technique is based on the establishment of a defect quotient - standard lifetime divided by actual lifetime.

[34] HAARHOF, F.E., "Maintenance Cost Control - Crucial role in the Profit Game", Factory, Morgan-Grampain Ltd. London, Nov. 1976; pp35-38.
Plant maintenance can save money with little investment of time and money. This article outlines the areas of the maintenance management program that are essential to achieving this end - clear objectives, firm maintenance plan, accurate record-keeping of actual performance, measuring performance, and corrective action based on feedback.

[35] HAMLIN, S.C., "Your Maintenance Management - Fit or Flabby", Factory, Maintenance Management (later Modern Manufacturing), McGraw-Hill Inc., New York, Jan. 1963; pp50-53.
Outlined is a Maintenance Fitness Questionnaire, designed to assist in the appraisal of maintenance effectiveness. The article describes how the questionnaire is used, when it is used and how ratings can be calculated and compared.

[36] HEPBURN, A.M. and LAWSON, J., "Maintenance Planning", Symposium Underground Mining Equipment Mainten-

ance, Harrogate, London, 1973, Paper 5; pp33-38 (Ref 4).
The factors that must be considered in planning for maintenance are outlined. The article further describes the types of maintenance, the legislation governing maintenance planning in the U.K. and the resources needed to effect proper maintenance in a mining environment.

[37] HERBATY, F., "Maintenance Management System: The Downtime Improvement Cycle", Plant Engineering, V30, N21, Oct. 1976; pp131-134.
Downtime control can be achieved through a repeating Downtime Improvement Cycle. Downtime is reduced each time the cycle is repeated. This article outlines, in some detail, the steps in a downtime control cycle: categorizing equipment by criticality; performing preventive maintenance; recording equipment breakdown; analyzing highly repetitive failures; determining and taking corrective action.

[38] HERBATY, F., "Maintenance Management System: Equipment Repair Records", Plant Engineering, V30, N23, Nov. 1976; pp195-197.
The recording of appropriate information concerning equipment breakdowns is essential to downtime control. This article discusses methods for recording equipment breakdowns. Three types of recordings are outlined - detailed-stage, intermediate-stage and broad-stage.

[39] HERBATY, F., "Maintenance Management System: Analysis of Critical Equipment Breakdowns", Plant Engineering, V30, N25, Dec. 1976; pp179-181.

At times, maintenance problems will be serious enough to justify a formal and immediate investigation. A specific procedure should be established for handling such problems. This article outlines some of the considerations that are necessary prior to the establishment of such a procedure.

[40] HERBATY, F., "Maintenance Management System: The Principle of Simultaneous Downtime", Plant Engineering, V31, N6, March 1977; pp136-138.
The simultaneous downtime approach is particularly important in maintaining large, complex, expensive equipment items with high downtime costs. This article defines the simultaneous downtime approach, explains the principle behind the approach and describes the basic procedure for applying the principle. A case study is also outlined.

[41] HERSHEY, T.M. and CLAIRE, F.V., "Using Computer Data in Maintenance Management", Plant Engineering, V33, N15, July 1979; pp95-98.
It is important for any maintenance department to have clear, concise and timely information on the performance of its maintenance operations. This paper looks at some computer generated reports that provide such information: work order performance; employee performance; backlog; equipment history; administrative reports; production reports.

[42] HILDERBRAND, J.K., "Maintenance Turns to the Computer", Cahners Books, Cahners Publishing Co., Boston, Mass., 1972.

This book presents a general discussion of the maintenance problem and a study of computer applicability to maintenance management. Separate chapters deal with specific areas of maintenance management such as cost control, work programs, preventive maintenance, materials control, training and replacement planning. In many of the chapters case studies are presented.

[43] HILDERBRANT, H.G., "Managing Lubrication at International Nickel", C.I.M. Bulletin, Oct. 1975; pp79-84.

This paper describes the steps taken to improve lubrication practices and procedures at International Nickel operations in the Sudbury District. The economic advantages of lubrication standardization, application and handling to improve machine life and reduce consumption are discussed. The author points out that the problems and solutions discussed are particularly applicable to trackless mining, crushing and milling operations.

[44] HILL, F.E. and LILLY, P.E., "Application of Maintenance Management Techniques to Underground Coal Mining Face Equipment", Symposium Underground Mining Equipment Maintenance, Harrogate, London, Final Technical Paper, Nov. 1979; pp20-25.

This article outlines the steps in the establishment of a maintenance planning department in underground coal mining operations in the U.K. The key role of planning in the areas of scheduling

major maintenance operations, coordinating management information and focusing resources to resolve critical problems is described, and the importance of close co-operation between maintenance and production personnel emphasized.

[45] HODGKINSON, A., "Aspects of the Use of Computers in Maintenance Management: Application to Maintenance Control", Terotechnica, V1, N3, March 1980; pp197-205.
This paper presents a case history of the use of computers for the control of maintenance. It deals specifically with the processing and provision of information designed to enhance the performance of an engineering maintenance department. The application is within a medium-sized company operating in the food processing industry.

[46] HORA, M.E., "Developing a Maintenance Training Program", Plant Engineering, V32, N7, March 1978; pp275-278.
Five steps to follow in developing a maintenance training program are outlined: establishing overall need; identifying areas for performance improvement; establishing a skills and resource inventory; designing an individualized program; instituting the program.

[47] JARDINE, A.K.S., "Maintenance, Replacement and Reliability", John Wiley and Sons, New York, N.Y., 1973.
This book shows how the procedures of maintaining industrial equipment in the process and manufacturing industries can be put on a systematic and quantitative basis. The relevant

statistics and engineering economics are covered but the essence of the book is a number of maintenance models for evaluating problems. Problem situations covered include replacement, preventive maintenance, inspection, overhaul and repairs, and scheduling maintenance procedures.

[48] JARDINE, A.K.S.(Ed.), "Operational Research in Maintenance", Manchester University Press/Barnes and Noble Inc., New York, 1970.
This book stems from twelve papers presented at the "Operational research in maintenance symposium", held in the U.K. in 1968. Each paper deals with the application of operations research techniques to different aspects of maintenance management. Aspects covered in the book include, problem formulation and solution procedures, mathematical models for replacement strategies, hire/own policy for dump trucks, optimization of maintenance crews, and maintenance management practices. The majority of the papers are of a case-study nature.

[49] JOHNSON, R.R., "Management of a Reliability/ Maintainability Department", Product Assurance Conference and Technical Exhibit Transaction, New York, June 7-8 1968; pp155-162.
This paper presents the observations and reactions of the director of Reliability & Maintainability for a company engaged in the military electronics business. Primary emphasis is placed on the areas of establishing goals, organization of the department and typical problems encountered.

[50] JONKMAN, J., "Maintenance Control at the Kennecott Minerals Company", Application of Computers and Operational Research in the Mineral Industry, Published by Society of Mining Engineers, New York, 1982; pp145-154.

This paper discusses the primary features and function of a maintenance control system developed by the Kennecott Mineral Company, Salt Lake City, Utah. The state-of-the-art technology that has been applied and the benefits that resulted from the system are described. Programs which are currently under development are reviewed and a summary of future applications is given.

[51] JUDE, E.A., "Management of Maintenance", Symposium of Underground Mining Equipment maintenance, Harrogate, London, 1973; pp49-64.

A review is made of the increased number of machines underground, the availability of machines for maintenance, the organization of manpower, and supervision to carry out maintenance. Reporting methods, documentation of information and replacement strategies are also considered. The report is based on coal mining operations in the U.K.

[52] JUUL, P.T., "Methods for Estimating Maintenance Work", Plant Engineering, V30, N21, Oct. 1976; pp169-171.

This paper presents a comparison of the four common techniques used in the estimation of maintenance work. The techniques covered include, foreman's estimating, statistical slotting standard, universal maintenance standards, and engineering standards. Worked examples are provided.

[53] JUUL, P.T., "Computerized Maintenance Management", Paul T. Juul and Associates Inc., Bellevue, Jan. 1982.

This publication presents a comprehensive description of the essential features of a computerized maintenance management system. The features covered in the document include work order system, cost control, stores-inventory control, preventive maintenance, reporting and recording and technical considerations. Mention is also made of methods of implementing such a program, anticipated problems, and some possible soluutions. Attached is a questionnaire for conducting self-evaluating surveys of maintenance management systems.

[54] KEGEL, W.G., "Managers Requirement for Maintenance", Mining Congress Journal, June 1971; pp27-31.

The topics covered in this paper include: the changes in maintenance management problems (coal mining in the U.S.); the mechanization of mining; the use of new design concepts to offset the lack of mechanics; the need for improvement in equipment and maintenance techniques; and the ultimate responsibility of management for solutions to these problems.

[55] KELLY, A., "Topics in Terotechnology: A Review of the Maintenance Management Problem", Terotechnica, V1, N4, July 1980; pp243-255.

This paper considers the increasing influence of availability and maintenance costs on industrial plant profitability. It emphasizes that the best time to influence such costs is before the plant comes into use. The paper shows that maintenance work is made up of two components-expected and unexpected. The paper also suggests a procedure for establishing a maintenance program and its organization.

[56] KELLY, A., "Maintenance Strategy, Organization and Control", International Mechanical Engineering Conference, Making Steam Plant Pay, Harrogate, England, May 1979; pp19-27.

This paper deduces the fundamental reasons for maintenance from a consideration of the structure and design of industrial plant. The importance of availability is emphasized and linked with the maintenance function and objective. The maintenance actions (repair, replace, etc.) are outlined and the policies which can be used for carrying out these actions are discussed in detail. Maintenance organization is discussed and a control model is outlined.

[57] KELLY, A., "Maintenance Management and Failure Statistics", Institute of Mechanical Engineers (London) Proceedings, V193, June 1979; pp253-259.

Many of the problem situations in maintenance and reliability involves probablistic variables. The modelling of such situations requires a basic understanding of failure statistics. This paper attempts to clarify the use and limitations of failure statistics in the field of maintenance. It describes the various applications of the different probability desnity functions and indicates their respective limitations. Mention is also made of the importance of failure data.

[58] KELLY, A. and HARRIS, M.J., "The Management of Industrial Maintenance", Newnes - Butterworth, March 1978.

This book describes an approach to be used in formulating a maintenance plan. Plant is regarded as a hierarchy of parts, ranked according to function and replaceability. The idea of "replaceability" is used to classify various plant items into permanent, complex replaceable and simple replaceable categories. The author explains that based on this categorization, the maintenance actions for each item can be decided on - also the timing. The sum of all such actions constitutes the maintenance plan.

[59] KING, T. and STEPHENSON, W.G., "Safe Operation of Quarry Vehicles", Quarry Management and Products, Institute of Quarrying Transactions, Dec. 1981; pp835-841.

An outline is made of current U.K. laws governing the safety of quarry machinery, and a description given of details of design and maintenance of such vehicles. The need for effecting improvement to machinery is emphasized and the importance of sound maintenance practices and management stressed.

[60] LAWSON, D.L., "Maintenance Information Reports", Plant Engineering, V32, N13, June 1978; pp121-124.

This paper explains how information reports can be used to provide management data for planning and controlling maintenance operations. Eight questions are provided too which the information system should provide answers. The paper highlights four aspects of maintenance control that should be reported on and the kind of reports necessary. Three basic types of management information systems are summarized.

[61] LAZENBY, W.W., "Organizing a Maintenance Department for Optimum Effectiveness", Plant Engineering, V34, N9, May 1980; pp83-85.
The concept of "optimum" can be applied to maintenance organizations of any size and level of maturity. The steps outlined in this paper for achieving the optimum state are: the setting down of specific personal characteristics for each of the maintenance positions; proper selection of supervisory personnel; establishment of job descriptions; establishment of degree of authority and lines of responsibility; and the creation of maximum cooperation between production and maintenance personnel.

[62] LEWIS, B.T., "Developing maintenance Time Standards", Farnsworth Publishing Inc., Boston, Mass., 1967.
This is a practical textbook on techniques and procedures for developing reliable standards for a wide range of maintenance operations, including already established engineered performance standards for hundreds of maintenance tasks. The text covers such areas as: concepts of maintenance time standards concepts of engineered performance standards; applying engineered performance standard in individual operations; procedures for planning and estimating with engineered performance standards; and setting up and monitoring an engineered performance standards program.

[63] LOCKARD, H.J., "Contracting versus In-plant

Maintenance", Mining Congress Journal, Oct. 1975; pp49-51.
Contract maintenance is defined. The five types are discussed including labour brokers, speciality, supplementary, continuous and intermittent, and total. The paper also outlines the areas to be explored before using contract maintenance including labor relations, comparative costs, quality of work and flexibility.

[64] LOGAN, W.A.D., "A Maintenance Management System-Concept, Implementation and Experience", European Offshore Petroleum Conference and Exhibition, London, Oct. 24-27 1978; pp133-140.
This paper outlines the fundamental features in a maintenance management program for a North Sea production platform. The paper describes, in detail, a program devised for an offshore operation and discusses the experience gained during the eighteen months of operation. Also mentioned are such aspects as location of control, effect of spare stocks on control location, and considerations for computer application.

[65] MACKINTOSH, S., "OPTIMA - A Management Information System at Nchanga Open Pit, Zambia", Institution of Mining and Metallurgy Transactions, July 1973; pp77-93.
This paper discusses the development of a technical information system at the Nchanga open pit in Zambia. The system is computerized and consists of modular subsystems, using common data files, as well as new or improved clerical procedures. The main applications of the system in the areas of production, maintenance and components assessment

are described.

[66] **MANN, L., "Increasing Productivity by Improved Maintenance Management", Terotechnica, V2, N3, Aug. 1981; pp205-210.**
Maintenance cost is rising faster than other costs attendant to operating a process plant. A number of variables affect this cost. It is therefore necessary to isolate maintenance costs and apply productivity indices to those activities. The types of indices discussed in this paper include those which measure planning, measure control of work force and monitor the entire maintenance system. The article also discusses some interpretations given to various productivity indices for maintenance.

[67] **MANN, L., "Maintenance Management", Lexington Books, D.C. Heath and Company, Lexington, Mass., 1976.**
This book presents a very good coverage of the concept of maintenance management. Emphasis is on computerizing the maintenance management program and the contents cover all the essential features to be included. The text covers such areas as: organizing maintenance operations; maintenance control system; job planning and scheduling; work measurement; preventive maintenance; appraising maintenance performance; maintenance budgets; training; and motivation.

[68] **MANSELL, D.W., "Vehicle Fleet Maintenance Management and Control", Quarry Mangers Journal, Sept. 1971; pp322-324.**
A maintenance system which pinpoints costs and expenses on vehicles - equipment and facilities

and identifies critical areas is described. The input to the system includes work orders, indirect labour and materials costs, vehicle inventory, mileage and fuels, and accounting control. Output includes, reports on vehicle exception, maintenance costs, indirect labour, garage performance, inventory levels and overall operating costs.

[69] MARINELLO, R.L., "Maintenance Time Standards", Plant Engineering, V30, N26, Dec. 1976; pp26-42.
One of the tools available to help control maintenance costs is maintenance time standards. No one standard will fit all conditions. Standards must be adapted to suit the maintenance situation involved. This paper provides a basic guide to maintenance time standards. It describes the various approaches to the setting up of time standards, how they are applied and how they are used to form the basis of a work measurement program.

[70] McCOY, R.R., "Program Maintenance for Lower Cost, More Uptime", Pit and Quarry, Oct. 1975; pp56-59.
A quarry maintenance management program is described covering such areas as job and equipment studies, maintenance instructions, preventive maintenance, cost control, recording, breakdown analysis and reporting. A system for educating personnel to accept the program is also described.

[71] McNEIL, T. and ROWAN, S., "The Planning and Practice of Maintenance Engineering at a Modern Colliery", Symposium Underground Mining Equipment Maintenance, Harrogate, London, 1973; Paper 1, pp1-10.

This paper lists a number of parameters which control the scheduling of maintenance jobs in an underground coal operation. It also describes ways in which men, machines and materials can be better utilized in realizing operational maintenance. Reasons are stated for an operational examination of underground equipment. Education in accepting this type of maintenance management is described.

[72] **McCULLOCH, R.A. and HURME, R.M., "Trades Training at Falconbridge", Canadian Institute of Mining Research, April 23, 1980; pp19-25.**
This paper discusses the introduction of a modular training program for heavy equipment mechanics at Falconbridge Nickel Mine. A description is given of the training of journeymen by the apprenticeship method and the integration of the modular system. The paper explains how and why a modular program was developed as a pilot project and its success.

[73] **MILLER, F.G., "A Maintenance Control Program for Large Diversified Plant Operations", International Plant Engineering Conference, Montreal, Quebec, June 1-3 1976; pp6.1-6.9.**
A computerized maintenance control program, capable of addressing both preventive and corrective maintenance and also allowing for emergency breakdown, is described in this paper. The general program is divided into five subsystems: work history, work orders, follow-up, accounting and inventory. The foundation of the program is work order generation and scheduling but it also includes inventory control, production control and

information feedback.

[74] **MULLEN, C.R., "Maintenance of Underground Machinery", Symposium of Underground Mining Equipment Maintenance, Harrogate, London, 1973; Paper 2, pp11-18.**
This paper examines the design of maintenance schemes in underground coal mines in the U.K. with regard to the planning, line organization, organization theory, personnel aspects, manpower planning and supervision. It stresses the importance of training for maintenance re: long term aims, training arising from proposed changes in working methods, refresher and specialized courses, and training of operatives to know the equipment potential.

[75] **NEWBROUGH, E.T., "Managing Maintenance Materials", Plant Engineering, V35, N7, April 1981; pp51-53.**
Maintenance materials are an important part of maintenance costs. However, an analysis of total maintenance costs usually shows that material costs are controllable. This paper examines some of the aspects of maintenance material management under three main headings - maintenance stores, material planning and material changes. Under these three headings, the author describes procedures to be followed, problems to be expected and guidelines for possible solutions.

[76] **NICOLETTI, B., "New Maintenance Strategies", Terotechnica, V1, N3, Mar. 1980; pp161-171.**
The current inflationary economic difficulties call for a greater rationalization of maintenance activities. At the same time, it is becoming

increasingly apparent that there is a connection between maintenance efficiency and production costs, repair costs, and hence revenue. In this paper, the choice between maintenance and replacement is examined from different standpoints: management, the micro- and macro-economic, and the social aspects. Conclusions are drawn as to a new direction for maintenance and the strategies necessary.

[77] **NOVAK, J.B., "Preventive Maintenance - What, How Much and Why", Transactions of the Society of Mining Engineers, V252, Sept. 1972; pp266-270.**
This paper describes preventive maintenance programs and controls, applicable in situations where maintenance actions are caused by breakdown or part failure and specification and documentation of detailed maintenance practices are minimal. Described are requirements of organization structure, program administration, implementation and operation, type of benefits expected, and actual benefits derived in selected areas. The paper is based on programs implemented at U.S. Steel Corporation, Pittsburgh.

[78] **PATTON, J.D., "Computerized Maintenance Management - Today", Advanced Instrumentation, V34, Part 2, 1979; pp251-255, Published by ISA, Pittsburgh, PA, 1979.**
Computers are the most significant force in modern maintenance management. They provide powerful data processing capability both in equipment that must be maintained and in maintenance management systems. This paper highlights an operational computerized maintenance management system (COMMS)

that has been developed from information described in literature, modified by the author's experience and enhanced by improvement in computer hardware and software. Illustrated are practical applications, reports, displays and scenarios of how computers can be used to assist maintenance management today.

[79] PAWSON, S., "Planning for Maintenance: The Broad View", Symposium Underground Mining Equipment Maintenance, Harrogate, London, March 14-16 1973; Paper 6, pp39-43.
This paper gives a broad view of the various aspects of maintenance planning. First, it is emphasized that clear objectives must be established before any planning can commence. The different types of maintenance are then discussed, and a description given of how they are applied to mining machinery. The paper explains that in designing a good maintenance program, it is necessary to specify the "what, when and how?" of maintenance - it shows how this can be done. Some allied factors are discussed, namely, how new equipment is dealt with, including defects and modifications, and other engineering services involved. The paper concludes by reiterating that, in today's highly mechanized mining industry, the maintenance activity demands a highly organized plan.

[80] PESKATOR, H.W., "A Preventive Maintenance Program for Water Plants", Annual Public Water Supply Engineering Conference, 18th Proceeding, Water Treatment Part 1, Champaign, ILL., Mar. 29-31 1976; pp177-187.

All preventive maintenance is based on one theory - it is better to keep out of trouble than it is to get out of trouble. Based on this theory, the author outlines nine basic care operations that he considers essential to any small plant. A method of establishing a preventive maintenance program is described and a case study of a program at a water utility is presented.

[81] PRIEL, V.Z., "Systematic Maintenance Organization", MacDonald and Evans Ltd., London, 1974.

This book provides many of the administrative/managerial techniques essential for setting up a maintenance management program. It adopts an analytical, do-it-yourself approach that can assist the maintenance manager in appraising his work and making necessary adjustments along the way. Many of the essential elements involved in the management of maintenance are covered including, organization of the department, planning the program, paperwork, scheduling, stores, control procedures, reporting and the human element.

[82] READER, D.K., "Problems in Preventive Maintenance Systems", Canadian Institute of Mining Reporters, V6, N4, April 23 1980; pp12-15.

This paper is based on a planned maintenance program in operation at Hudson Bay Mining and Smelting Co. The problems encountered during the eight years of program development are discussed with special emphasis on the people involved, their attitudes and experience and the management organization. The paper also summarizes the progress made since the implementation of the

program and some of benefits derived.

[83] RIFKIN, W., ARGUE, E. and ROGALA, K., "Manage Generation Maintenance Cost - Effectively", Power, V125, N9, Sept. 1981; pp113-116, 119-121.
This paper describes a computerized system for power-generation maintenance at the Long Island Lighting Company. The description covers the eight critical areas of the system which include, equipment history, budget/cost control, work scheduling, long range planning, preventive maintenance, materials management, performance measurement and personal training. The system combines these eight areas into one comprehensive data base. Benefits derived are outlines and plans for expansion discussed.

[84] ROBINSON, W.V., "Maintenance Scheduling and Inventory Control Computer Systems at the Iron Ore Company of Canada", Preprint No.75-AR-332, Fall Meeting, SME, AIME, Sept. 1975; 24p.
This paper discusses the preparation, development and installation of a computerized maintenance management system at the Iron Ore Company of Canada. Detailed are three of the major areas of application of the computer; maintenance scheduling, inventory control and purchasing.

[85] RUTTER, C.G., "Developing and Managing a Preventive Maintenance Program", American Institute of Plant Engineering, West Plant Engineering Maintenance Conference Procedings, San Francisco, CA, Nov. 3-5 1970; Session 28, pp9-10.
The guidelines presented in this paper are designed to assist in implementing a cost-effective

preventive maintenance program, within the framework of most plant requirements. The critical areas of the program are described in some detail and include equipment history, preventive scheduling, inventory control, breakdown analysis, analysis of repetitive failures and equipment retirement. Management techniques to assist in the elimination of bad practices are explained.

[86] SLATER, R.G., "Maintenance Management Through Diagnosis", A Paper Presented at the Mechanical Failures Prevention Group Symposium, May 19th 1977; Published by Rand Corporation, Paper 5867, June 1977; 14p.

The high cost of military vehicle maintenance has caused an increasing interest in the development of improved vehicle design and diagnostic procedures, with the objective of reducing costs. This paper is concerned with one such procedure - periodic health screening. Specifically, the paper examines the essential elements of a periodic health screening program and in particular the significance of failure models. Discussions are centered around the types of failure models, analysis data collection, and a monitoring system.

[87] SCHWANN, H.T., "Maintenance Organization: What's the Best for You", Mill and Factory, Dec. 1967; pp39-45.

Do you know the pros and cons of maintenance organization? Many factors obviously come into play and they are all inter-related. Yet, no clear-cut concept can cover all plants. Often it is a variation or combination of the centralized

measure does not suffice; a well balanced maintenance planning/scheduling system should provide a complete source of accurate data and be equipped with suitable indexes that can assist in assessing its effectiveness.

[91] SMITH, R.A., "Plant Management and Maintenance", Colliery Guardian, 229 (8), Aug. 1981; pp387-395. This paper reviews the U.K. coal board arrangements for the management and maintenance of plant and equipment. The cost of maintenance, plant reliability, operational framework, training and education, maintenance planning, and computeraided plant management are all discussed.

[92] SNEAD, N., "Computerized Maintenance", Pit and Quarry, Oct. 1972; pp99-102.
A contractor's system for computerized cost calculations and continuous monitoring of maintenenace performance. A number of worked examples are provided.

[93] SPARKS, D.A., "Computerized Maintenance Management", Mining Congress Journal, 66 (8): Aug. 1980; pp37-41.
This paper describes the operation of a computerized preventive maintenance program in a coal mining operation. The program provides information on the age of selected parts of production machines and support equipment. These selected parts are called preventive maintenance units (PMU's). Once a part has been declared a PMU, it becomes a member of a computerized system that stores relevant data.

and area shops. Here are an expert's helpful pointers plus two case studies.

[88] SHEPPARD, D.F., "Designing a Small-plant Preventive Maintenance Program", Plant Engineering, V33, N3, Feb. 1979; pp119-122.
Because of the high developmental costs associated with preventive maintenance programs, they should be tailored for particular situations. Small plants generally require less sophisticated programs than large plants. This paper outlines a step by step approach that can serve as a guide in designing preventive programs for small operations.

[89] SLAWSON, H.C., "Management Aspects of Maintainability and Maintenance", 8th Reliability and Maintainability Conference (Annals of Assurance Sciences, V8), July 7-9 1969; pp460-465.
Maintainability analysis and maintenance analysis are the keystones on which the development of an intergrated logistic support system is based. The role of these two types of analyses is difficult to keep in perspective and is generally misunderstood. This paper examines the relationship between maintainability analysis and maintenance analysis, the interface with other program elements and the influence of logistics engineering management.

[90] SMITH, G.W., "Maintenance Planning/Scheduling", Plant Engineering, V23, N3, Feb. 1969; pp57-59.
This paper describes various methods by which the effectiveness of maintenance planning/scheduling can be assessed. It emphasizes that a single

[94] STEWART, R.E. and MANNING, R.F., "A Practical Computer System to Assist with Equipment Replacement", Mining Magazine, March 1980; (Ref5), pp263-268.

At the Kennecott Copper Corporation in the U.S. a computer package called Equipment Replacement Guide (ERG) is used to evaluate equipment replacement alternatives. ERG includes all the important economic factors and allows management to examine replacement decisions under various operating conditions. This paper describes the package including its benefits and limitations.

[95] STEWART, R.E., "Proper Equipment Replacement Timing - A Key to Replacement Economy", 82nd Annual General Meeting C.I.M., Toronto, Canada, April 1980; Paper 55, 22p.

This paper reviews economic replacement theory and describes how it can be applied to assist management with equipment replacement decisions. An analysis of an eight unit loader fleet is used as an example, showing the economics of replacement under a number of operating scenarios.

[96] TETTEMER, J.M., "Evolution of a Successful Maintenance System", Proceedings of the Special Conference - Water Forum, San Francisco, CA., Aug. 1981; V1, pp112-119. Published by A.S.C.E., New York, N.Y., 1981.

This paper gives a complete description of a study which led to the establishment of a new maintenance management system. The benefits and the dollar cost savings incurred as a result of the system are also discussed. The study was developed specifically for a Flood Control Dis-

trict but, in the opinion of the author, is applicable to most major maintenance functions.

[97] THOMPSON, P.N., TEALE, C.W. and Richardson, R., "A Computerbased Production Information System", 16th Application of Computers and Operational Research in the Mineral Industry, S.M.E., 1979; Chapter 1, pp3-15.
A description is given of a trial development and installation of a computer-based information system at a colliery in the U.K. The capability of the system includes monitoring and controlling of such activities as stores, material control, plant maintenance, plant records, and personnel.

[98] TOMLINGSON, P.D.,"Types of Maintenance Organizations" Plant Engineering, V33, N8, April 1979; pp315-317.
A number of factors have influenced the formulation of different types of maintenance organization. This paper describes how some of those organization types developed, giving reasons for their development. The types of organization described include: line, craft, area, central and a combination of area and central. The factors to be considered before deciding on an organization type are outlined.

[99] TOMLINGSON, P.D., "Balancing Workloads of Regular and Special Maintenance Projects", Plant Engineering, V30, N24, Nov. 1976; pp97-100.
In addition to ongoing maintenance activities, major capital projects - including equipment installation and modification - are sometimes managed by the maintenance department. This paper

describes a systematic approach to the planning and scheduling of both capital projects and maintenance activities. The need for project control, labour control, material control and the setting of priorities is emphasized. Control techniques such as PERT and CPM are explained and recommended.

[100] **TREGELLES, P.G., "The Contribution of Measurement and Computation To Improve Control and Management of Mechanized Mining Systems", Mining Engineer (London); 141 (241); Oct. 1981; pp199-206.**
The article defines systems control and explains how it is that small computers have produced a dramatic step forward, towards improved plant utilization. The paper considers the changes which this new technology is introducing into the four related fields of systems design and reliability, plant and equipment maintenance, systems operation, and automation.

[101] **VARGAS, K.J., "Managing Plant Turnarounds", Chemical Engineering, June 1979; pp116-130.**
To complete a turnaround as smoothly and quickly as possible requires careful, detailed planning and follow-through. This paper, based on operations at Eldorado Nuclear Ltd., offers a proven step-by-step method to accomplish this.

[102] **WEAVER, J. AND MORGAN, R.D., "The Application of E.D.P. to Plant Listing Maintenance Procedures", Symposium Underground Mining Equipment Maintenance, Harrogate, London, 1973; Paper 12, pp101-112.**
A description is given of the manual system of

plant listing in use in the South Wales area of the National Coal Board (U.K.) and of how it lends itself to E.D.P. (electronic data processing). A data file, bearing all known information about each item of plant and equipment, is created and by feedback the file is kept up to date. The listings, schedules and statements extracted each week from the computer output are outlined.

[103] **WILKINSON, J.J., "How to Manage Maintenance", Havard** Business Review, March-April 1968; pp100-111. Substantial opportunities now exist for increasing the productivity of maintenance personnel and reducing costs. This article offers some guidelines as to how these can be achieved. The paper examines popular misconceptions, areas of critical need and some general principles. It also describes some basic control tools and reporting procedures.

[104] **WEISS, W.H., "Improving the Quality of Maintenance",** Plant Engineering, V34, N19, Sept. 1980; pp99-101.

Maintenance Managers are becoming more aware of the benefits of a well-planned maintenance quality control program. As outlined in this paper, it can improve the maintenance function, increase the efficiency of personnel, improve service to production and, most important, reduce maintenance costs. Areas to be examined and what to look for are recommended in the paper - these include, purchasing practices, maintenance performance, workforce, training program, preventive maintenance practices and planning and scheduling procedures.

REQ. NO. 3-9094

CONTRACT REPORT NO. OSU83-00131

A REVIEW OF MINE MAINTENANCE IN CANADA

PREPARED FOR CANADA CENTRE FOR MINERAL AND ENERGY TECHNOLOGY

(CANMET)

UNDER

DSS CONTRACT NO. 20 SU 23440-3-9094

PREPARED BY: Queen's University
131 Union Street
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November 1983

286 pp

OCT 26 1984
MICROMEDIA

ABSTRACT

This report presents a state-of-the-art review of maintenance management as applied to the mining industry. It is based on a comprehensive literature review and field visits to twelve Canadian mining operations.

Effective management of the maintenance function is a requirement of any mining operation. Control of the function requires a sound maintenance management program, designed to ensure optimum performance of equipment for the lowest possible cost and to provide for the supply of feedback data to demonstrate the achievement of these aims. Because of the diverse nature of mining activities, it is not possible to outline a simple, "one-for-all" management program. Each operation must be considered individually.

This report is written as an aid to mine operations faced with the task of organizing a maintenance management program. It provides a step-by-step guide of what is involved in developing and implementing such a program. With this kind of information it is possible for a mine manager to develop a new program, evaluate an existing one or upgrade a weak one and integrate the program into the overall mine organization to achieve a more economical operation.

The effectiveness of a maintenance management program is a direct result of the effort put forth in developing same. However, proper functioning can only be assured if certain fundamental features are included in the program. These features which are covered in this report include:

1. Supporting Features

    - attitude
    - maintenance objectives and policies
    - total life-cycle maintenance
    - maintenance annual report
    - maintenance management manual

2. Essential Features

- maintenance organization
- systems and procedures
- maintenance strategy (plan)
- planning and scheduling
- information system and control

Special attention is also given to computerization, application of analytical techniques and implementation of a program . Emphasis throughout the report is placed on the problems that are encountered and practices that have proven successful.

Visits to the twelve Canadian mining operations revealed that there is much to be desired of current maintenance management programs. Although many operators are aware of the need for improved maintenance management, the programs in place are not comprehensive enough to achieve the desired results. Some of the common problems include: lack of support from top management, lack of expertise to develop program, lack of knowledge of systems and practices, poorly developed and implemented programs.

FOREWORD

This report was prepared in fulfillment of Contract No. 20 SU.23440-3-9094 between Supply and Services Canada and Queen's University, under the general direction of the Scientific Authority, R.J.R. Welwood, representing the Canada Centre for Mineral and Energy Technology (CANMET).

The field surveys, associated studies and resulting Final Report were done by Terrence M. Evelyn of the Mining Engineering Department of Queen's University, under the supervision of Dr. J.H. Brown. Dr. A.K.S. Jardine of the Royal Military College, Kingston assisted in formulating the approach and guided in making operations research applications in mine maintenance.

Recognition and appreciation are extended to those companies which contributed to the survey which made this report possible.

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NOTATIONS

β	Shaping Constant in Weibull Distribution
η	Scaling Constant in Weibull Distribution
ν	Standard Deviation/Mean Ratio
σ	Standard Deviation
μ	Mean
ρ	Cost Ratio - Optimum/Replace only on Failure
$\lambda(t)$	Failure Rate
C	Maintenance Cost as a Percentage of Equipment Replacement/Value
C_f	Cost of a Failure Replacement
C_p	Cost of a Preventive Replacement
$C(t_p)$	Total Replacement Cost per Unit Time
$f(t)$	Probability Density Function of Failure Times
$F(t)$	Cumulative Probability Function of Occurrence of Survival
H	Expected Number of Failures in an Interval
i	Order Number
	Constant
k	Cost Ratio - $\frac{C_f}{C_p}$
L	Maintenace Lost Time as Percentage of Scheduled Production Hours
$M(t_p)$	Mean Time to Failure of Failure Distribution
N	Sample Size
P	Mean Estimation in Weibull Analysis
$R(t)$	Reliability Expected as a Function of Time
t	Time Interval as a General Variable
t_p	Replacement Interval or Age
$t-t_o$	Weibull Time Factor (t_o is Weibull Constant)
W	Maintenance Waste as a Percentage of Total Output
X	Total Maintenance Cost in Base Year
y	Total Cost of Maintenance Lost Time in Base Year
z	Total Cost of Maintenance Waste in Base Year

CMMP	Computerized Maintenance Management Program
CPM	Critical Path Method
DIC	Downtime Improvement Cycle
EOQ	Economic Order Quantity
EPS	Engineered Performance Standards
MMP	Maintenance Management Program
MTM	Motion Time Method
pdf	Probability Density Function
PM	Preventive Maintenance
PSOD	Principle of Simultaneous Downtime
UMS	Universal Maintenance Standard
WO	Work Order

Chapter 1

INTRODUCTION

Maintenance has been defined as: "Those activities required to keep a facility in as-built condition and therefore continuing to have its original productive capacity." (69) In the present text, management of maintenance refers to the planning, organizing, coordinating, staffing and controlling of the complete support activity for the entire operating area.

No other industrial function, with the possible exception of research and development, involves a wider range of activities than that of maintenance. (84) In fact, maintenance embraces so many activities that it should be considered an industry in itself. In this regard, management of the maintenance function abounds with problems and satisfactory support service cannot be achieved unless its activities are as well set up as those of production.

In many operations, notably the processing industry, the importance of maintenance equals that of production. However, there often exists a grave disparity between the management of the two functions. (84) Many managers are inclined to be production oriented and fail to recognize maintenance as an intrinsic part of the overall operation. While all their efforts are concentrated on producing more and reducing costs, maintenance seems to distract them from their goals and reduce their achievements. Unfortunately, trouble-free production can only be achieved by effective maintenance and good maintenance is only possible if it is well managed.

Although the importance of maintenance has never really been disputed, management of the function has been a long-neglected field. (69) For over half a century, industry has been applying the techniques of scientific management to the repetitive activities in the operations areas. However, it was felt that since maintenance tasks were not repetitive in the same way as those of operations, maintenance did not lend itself to similar applications. Recent developments in such disciplines as industrial engineering, operational research, management science and systems engineering have convinced management that maintenance is amenable to the same sort of applications as operations.

During the past decade, maintenance management has been elevated from an art, closer to a science. (69) This elevation was due, in part, to the development of formal management programs and to the application of procedures, which have, in the main, quantified items that were not previously quantified. Various analytical techniques such as failure statistics, indirect work measurement and mathematical modelling have evolved to the point where they have become useful in solving many of maintenance's traditional problems. The use of these techniques has served to remove the subjective element from maintenance decision-making. Unfortunately, however, with the exception of a few large companies, maintenance has remained a neglected function of industry. (57) Many managers still view maintenance as a tolerable activity, a "necessary evil" (84) and fail to recognize the positive contributions that proper management of the function can make to improved productivity (see Table 1.1).

1.1 The Need For Maintenance Management In The Mining Industry.

Within the last twenty years, mining in Canada and elsewhere has experienced a significant growth, from a labour intensive industry to a capital intensive one. This change which has been accompanied by a simultaneous increase in both size and complexity of equipment has imposed considerable problems on the management of the maintenance function. Today, maintenance of mining equipment is so complex and important from a cost and production standpoint that the organization, personnel, procedures, planning, reports and records must be set-up in a engineering-like manner to be successful. (7) Anything short of a formal maintenance management program will prove inadequate to the control of the maintenance function.

In today's mining industry, plant and equipment are

Table 1.1 Typical Productivity* Ranges For Various Maintenance Situations (68) (Survey Conducted by Industrial Engineering Dept. of Louisiana State University, U.S.A., 1980)

Maintenance Situation	Productivity-Range (Percent)
No formal planning - scheduling. Minimal work order system. No measurement	30 - 50
Formal planning - scheduling. Functioning work order system. No measurement	50 - 70
Formal planning - scheduling co-ordinated with measurement system. Functioning work order and control systems	70 - 90
Formal and complete maintenance management program, including all essential elements	90

---

* Productivity is based on ratio between some measured aspect of maintenance activity and some pre-determined standard.

much more automated, much larger and very much more expensive to own than ever before. (7) Because of the high costs associated with maintenance resources and equipment unavailability, the management of maintenance has become a critical factor in company profitability. In the not-too-distant past, the cost of maintenance was so insignificant that management got away with very little surveillance of the expense. (68) Unfortunately, however, the picture has changed. The cost of maintenance has been on the increase, in the past few years more than ever before. A survey (81) conducted among chemical plants in the U.S. reported that the cost of maintenance climbed by 15% between 1970-1974 and by some 20% between 1974-1978. A similar survey (81) of the ten top petrochemical companies in the U.S. reported a spending of $1.2 billion on maintenance in 1977, a 15% increase over the previous year. Projections (81) at the time also indicated that these companies would experience a 25% increase, over the 1977 figure, in their maintenance budgets by the mid 1980's.

Moreover, the current scale of maintenance requirements is indicated by the fraction of operating budgets that are identified with the function. For example, for a large, highly mechanized mining operation the maintenance function can account for as much as 55% of the operating budget. (7) In the U.K., as recently as 1978, the National Coal Board reported that maintenance accounted for approximately 60% of its operating budget. (68) Clearly, at these levels, the mine manager with his eyes on bottom line profits must examine the systems and techniques by which maintenance expenditures can be controlled.

Even more important, maintenance technology has been rapidly changing during recent years. (81) The shift in the nature of the mining industry, from labour to capital intensive, has made this change a necessity. Large equipment cannot be operated until it breaks down nor can it be repaired on the spur of the moment; a significant measure of planning and organizing is essential. Therefore, the old concept of emergency replacement (operate equipment until it fails) which is still very common in many mining operations has given way to sound preventive maintenance, and even this has been upgraded to include on-condition and condition-monitoring. This evolution in the maintenance function has made the planning and controlling of maintenance activities much more difficult and has resulted in the need for a similar evolution in the management support necessary to provide proper direction to the function.

Mine maintenance should no longer be considered routine. The combined effect of escalating costs (maintenance and unavailability) and rapidly changing technology has made proper management of the function an absolute necessity. Crisis-oriented systems, familiar to many mining operations, are doomed to fail since they are incapable of meeting the new management demand in the maintenance workplace. The answer is formal maintenance management - a well-designed maintenance management program, administered by personnel who are experienced in handling sophisticated planning systems and supported, in many cases, by some degree of computerization.

1.2 The Maintenance Management Program.

Management of the maintenance function is not simple. The non-repetitive nature of many maintenance tasks makes planning, scheduling, and, most of all, cost control very difficult. Many of the conventional management techniques which work so well in production, do not work so well in the maintenance environment. Studies (55) have shown that because of obsolete maintenance management practices the productivity of most maintenance departments is only 30 to 50%, often through no fault of the employees. Employees spend a significant part of their time waiting or on non-productive tasks such as: (55)

- looking for foreman to get job assignment
- visiting work site to find out what must be done
- multiple trips for tools and materials
- seeking out spare parts
- waiting for other crafts to finish
- waiting due to lack of adequate information
- losing time because of countermanded orders.

A comprehensive, well-designed maintenance management program (see Figure 1.1) can provide solutions to many of these problems. (21) The objectives of such a program can be manyfold but, in general, most organizations require a program that provides an information system that will: (69)

1. Optimize plant and equipment performance.
2. Minimize maintenance costs in view of the overall objective of maximizing profits.
3. Inform all levels of management of the performance of maintenance so that corrective action might be taken when necessary.

In order to achieve these objectives the program must be based on the development of certain essential features:

1. An effective organization with clearly defined responsibilities.
2. Clearly established systems and procedures.
3. A strategic maintenance plan.
4. Sound planning and scheduling procedures.
5. An effective information system based on the generation of data from records and reports, on all aspects of the maintenance operations.

In addition there must be, in place, certain supporting features which will create the right environment for proper functioning of the program. These features include management's attitude to maintenance, maintenance objectives, maintenance policies, total life-cycle maintenance, maintenance annual report and the maintenance management manual.

It is important to note that there is no single set of features specific to mine maintenance management. (49) Both the essential and supporting features mentioned above are basic to any maintenance management program. However, depending on the area of application, local circumstances will vary and the importance and extent of application of each feature will differ. Within the mining industry, programs will vary depending on such factors as company policy, type of equipment, size of operation, whether the company is engaged in underground or surface mining and the general

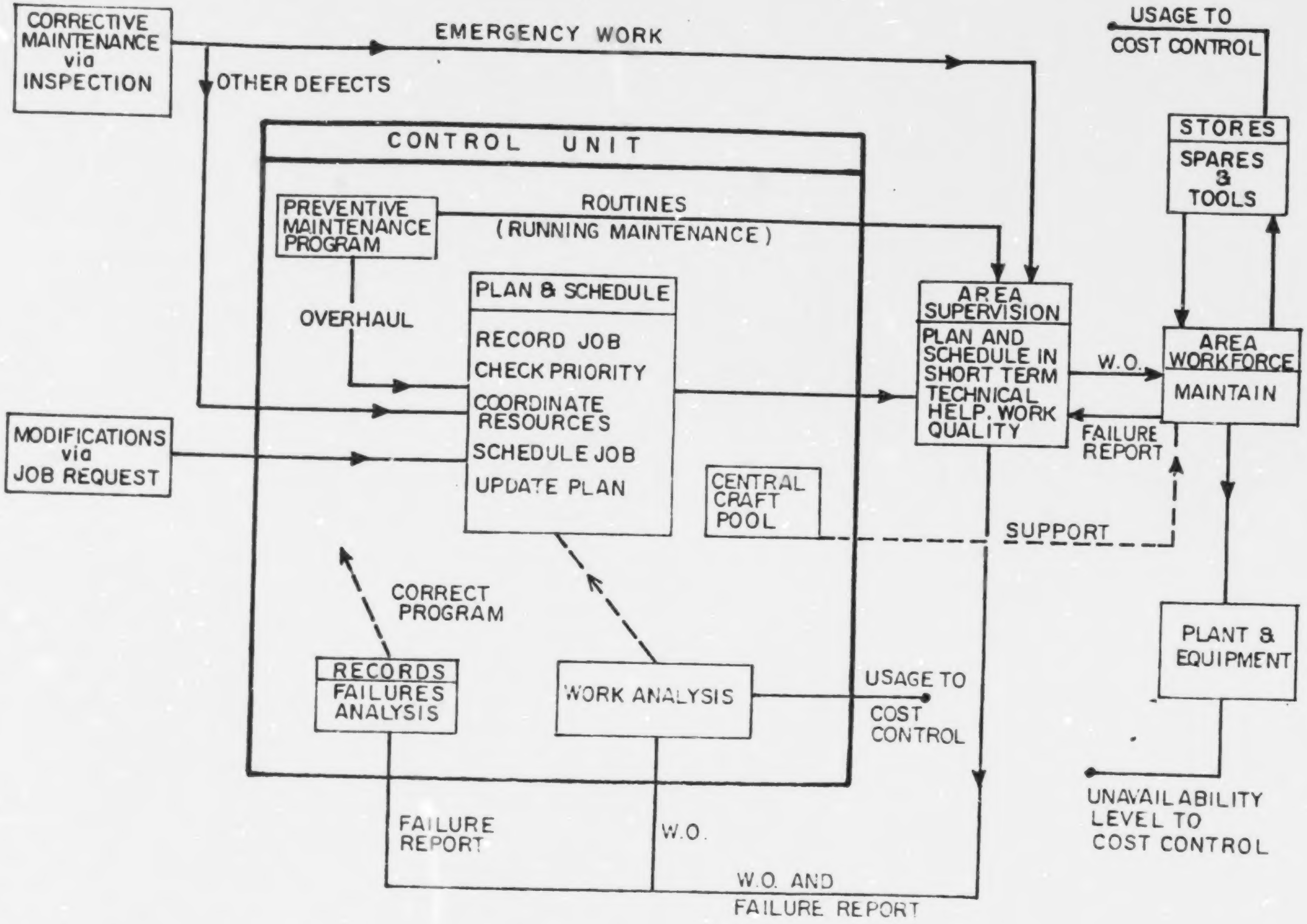

CORRECTIVE MAINTENANCE via INSPECTION
EMERGENCY WORK
OTHER DEFECTS
USAGE TO COST CONTROL
STORES
SPARES & TOOLS
CONTROL UNIT
PREVENTIVE MAINTENANCE PROGRAM
ROUTINES (RUNNING MAINTENANCE)
OVERHAUL
PLAN & SCHEDULE
RECORD JOB
CHECK PRIORITY
COORDINATE RESOURCES
SCHEDULE JOB
UPDATE PLAN
MODIFICATIONS via JOB REQUEST
AREA SUPERVISION
PLAN AND SCHEDULE IN SHORT TERM TECHNICAL HELP, WORK QUALITY
W.O.
AREA WORKFORCE
MAINTAIN
FAILURE REPORT
CENTRAL CRAFT POOL
SUPPORT
CORRECT PROGRAM
RECORDS
FAILURES ANALYSIS
WORK ANALYSIS
USAGE TO COST CONTROL
PLANT & EQUIPMENT
UNAVAILABILITY LEVEL TO COST CONTROL
FAILURE REPORT
W.O.
W.O. AND FAILURE REPORT

Fig. 1.1 A model of the complete maintenance management system (57)

philosophy of mangement. These factors must be given consideration prior to developing a program since they will determine the importance and extent of application of each of the abovementioned features.

The development of a maintenance management program which includes all the above features will result in a "loop of action" (84), illustrated in Figure 1.2. When properly implemented, this loop is self-regulating and provides the administration with the necessary feedback for effectively monitoring, controlling and upgrading maintenance performance. The basic program should always be flexible, to adjust to on-going changes within the maintenance department and it should also be tailored to fit into the specific needs of the individual organization.

A number of benefits (see Table 1-2) can be derived from a good maintenance management program but more important, it can result in improved maintenance productivity by providing the following: (55)

- uniform methods to initiate work
- procedures to approve and authorize work
- clear instructions
- making materials and tools available when needed
- agreement in job priorities
- work programs based on manpower capacity
- quality control programs
- personnel safety programs
- inventory information on maintenance materials and spare parts
- recording of man-hours, materials and costs
- development of maintenance history and downtime records
- information on equipment performance and failure analysis.

Moreover, a well designed program can help to reduce the paperwork of front-line supervisors thereby allowing them to spend more time supervising jobs and solving specific technical, as well as, "people" problems. (55) Such a program will furnish the administration with timely information

Table 1.2 Benefits of a Good Maintenance Management Program (84)

Factors	Important For
(a) Financial Benefits	
1. Extended equipment/plant life	Utilization of capital
2. Uninterrupted production	Utilization of capacity
3. Reduced production delays	Market Schedule
4. Reduced costs of repairs	Maintenance economy
5. Less stand-by equipment	Equipment utilization
6. Improved equipment replacement	Unit costing
(b) Organizational Advantages	
1. Co-ordination between production and maintenance	Internal planning
2. Manpower planning	Manpower utilization
3. Improved communication	Co-ordination of operations
(c) Technical Advantages	
1. Improved equipment suitability	Optimum production facilities
2. Build up of technical data	Information and technical services
3. Improved maintenance schedules	Plant availability
4. Improved plant condition	Operating efficiency
(d) Human Considerations	
1. Increased safety	Production economy
2. Improved housekeeping	Worker's morale
3. Less friction, better operations	Industrial relations

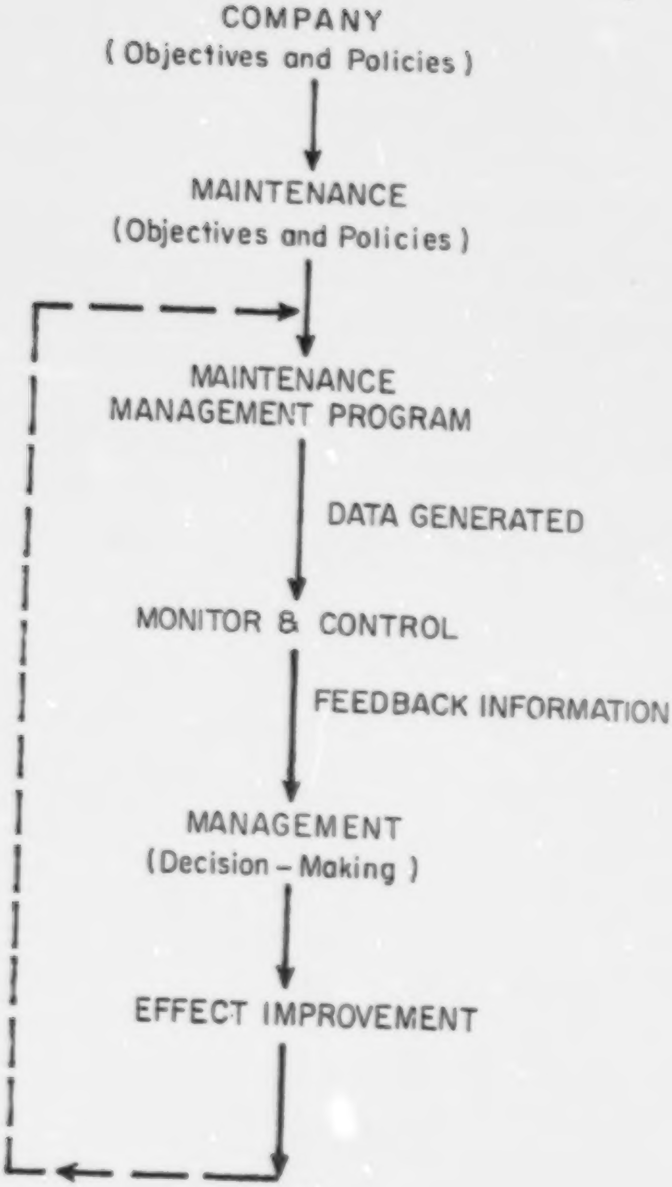

COMPANY
(Objectives and Policies)
MAINTENANCE
(Objectives and Policies)
MAINTENANCE MANAGEMENT PROGRAM
DATA GENERATED
MONITOR & CONTROL
FEEDBACK INFORMATION
MANAGEMENT
(Decision - Making)
EFFECT IMPROVEMENT

Fig. 1.2 The loop of action approach (84)

about work progress, backlog of jobs, jobs scheduling, performance levels, and variances from budgets which will allow better control of the many maintenance activities.

From information available in the literature (2,55,81), both the manufacturing and the airline industries have made significant progress in the development of maintenance management programs. Although very little quanititative data is available, companies in both areas have reported marked improvements in their maintenance operations, subsequent to the introduction of maintenance management programs. In the mining industry, there is some evidence that a few companies have introduced maintenance management programs. Those that have introduced such programs have reported improvements in the areas of equipment availability and maintenance man-hours per tonne of product. The results of two separate programs (15,19) are illustrated in Figures 1.3, 1.4 and Figure 1.5. However, data shown are not current and up-to-date information is not readily available.

1.3 Objective of Thesis

The objectives of this thesis are twofold:

(a) It aims to develop a clear and organized state-of-the-art literature review of maintenance management, to provide both a guide for mine maintenance managers in evaluating their work and the information on which improved methods might be devised.

With this objective in mind, the various aspects of a maintenance management program are covered, including techniques that are particularly suited to mining application. In brief, the aspects covered include:

- supporting features of a program;
- essential features of a program;
- computer application;
- analytical techniques;
- implementing a program.

(b) By examining current mine maintenance programs in

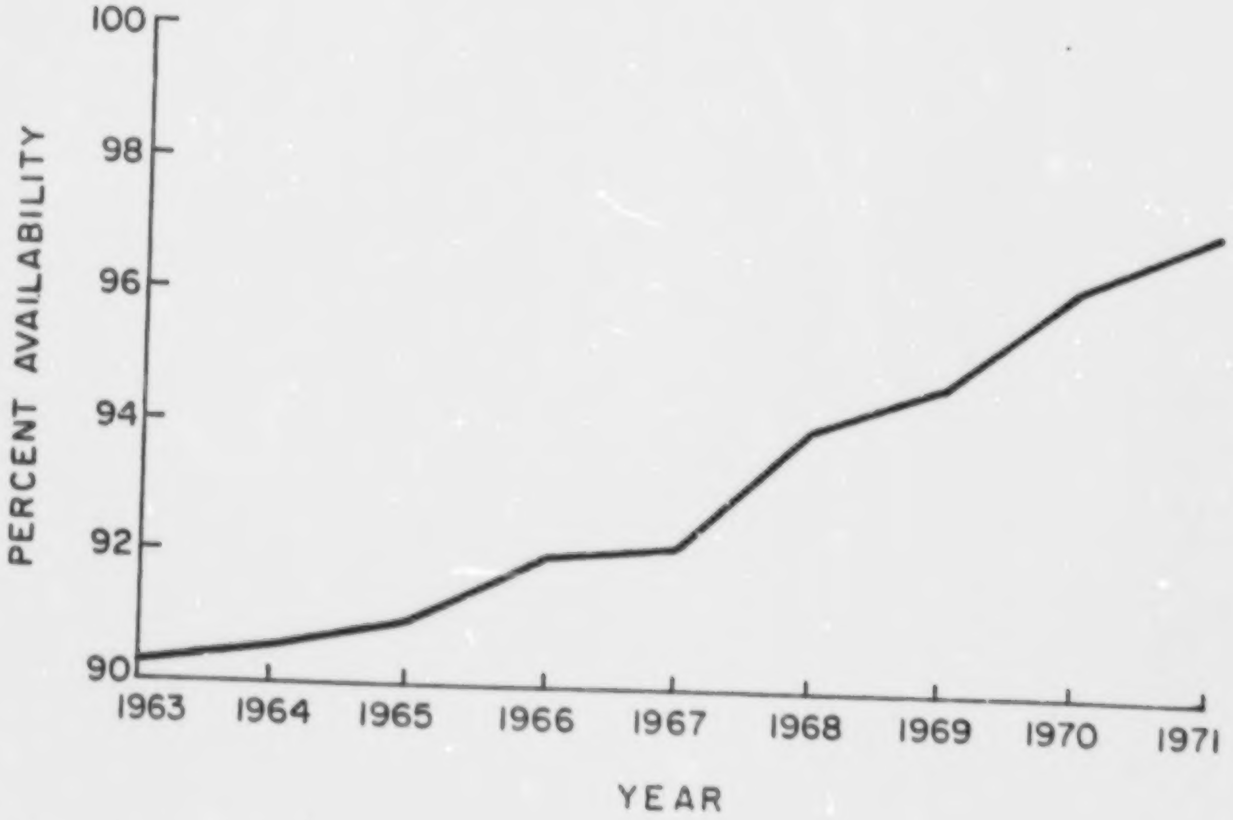


Fig. 1.3 Plant and equipment availability
Algoma's Mac Leod Mine, Wawa, Ontario (19)

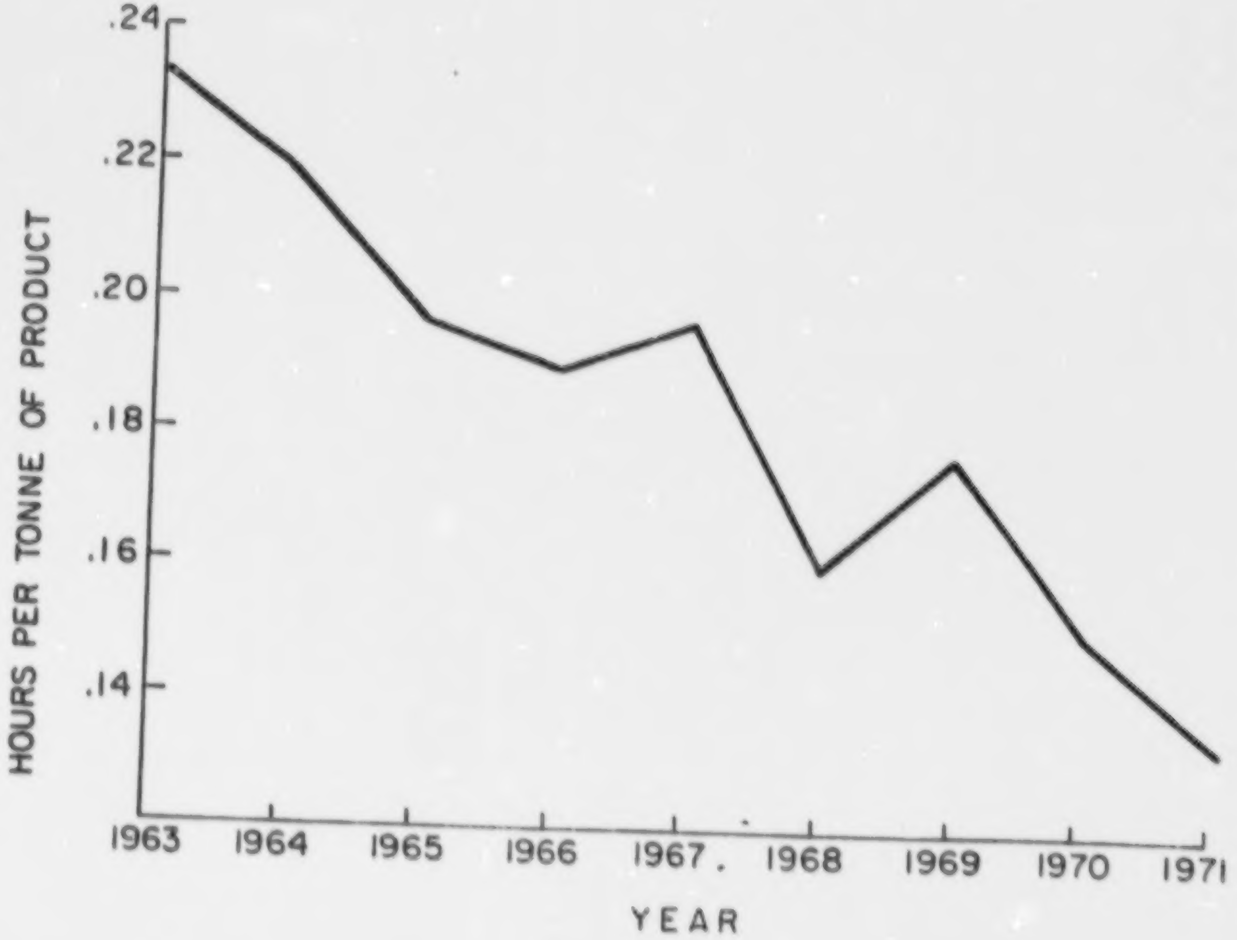


Fig. 1.4 Maintenance manhours per tonne of product
Algoma's Mac Leod Mine, Wawa, Ontario (19)

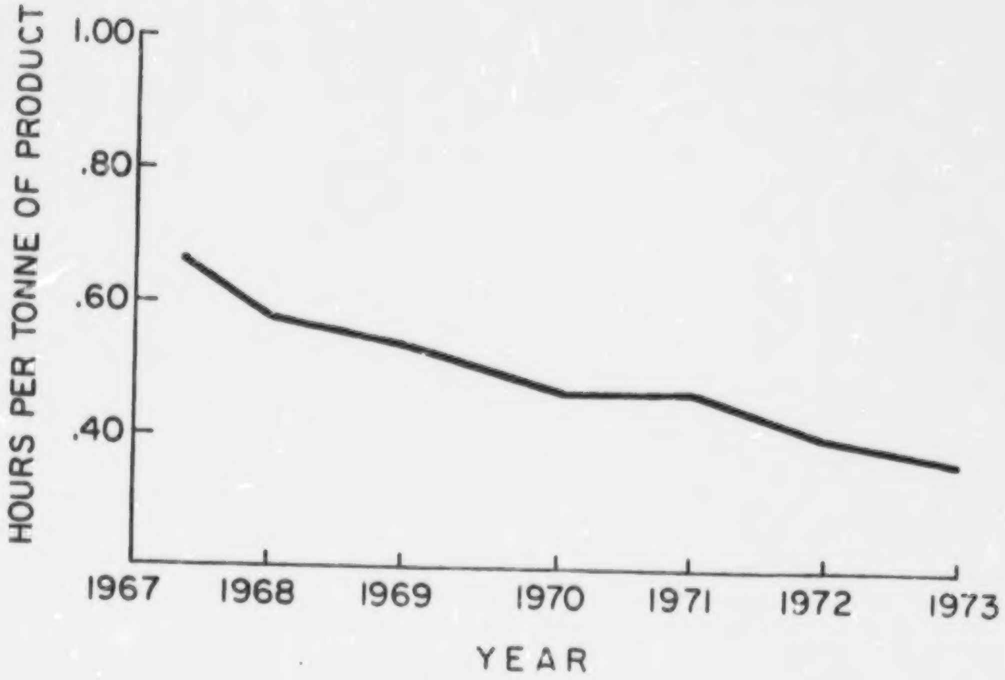


Fig. 1.5 Maintenance manhours per tonne of product
Quebec Iron and Titanium Corporation, Tracy, Quebec (15)

Canada, it aims to provide an organized statement of systems and arrangements now in use. This review will include descriptions and operator-evaluations of the methods by which Canadian mines are currently carrying out the following activities in their maintenance departments:

- management, organization and budgeting;
- generation and use of records, including breakdown;
- repair and parts inventory data;
- preventive maintenance planning;
- personnel development and retention;
- crisis reaction.

In each of these areas, the systems in use, advantages, shortfalls and requirements have been determined, both as perceived by individual users and in comparison with information obtained from the available literature.

It is hoped that this analysis can be used as a handbook by mine maintenance personnel who are faced with the task of evaluating a maintenance management program or upgrading an existing one.

Chapter 2

THE MAINTENANCE MANAGEMENT PROGRAM - SUPPORTING FEATURES

Maintenance management may seem complex when viewed as a whole, but when reduced to its component parts and given the support it requires, it becomes simple and easy to understand.

The effectiveness of a maintenance management program is greatly influenced by the organizational environment in which it exists. Regardless of how well a program is designed, it is doomed to fail unless it receives the proper support, and the right attitude is displayed towards the maintenance function.

Certain fundamental features, designated "essential features" in this text, are vital to the proper functioning of a maintenance management program. However, certain other features which are referred to as "supporting features" are also very important. These supporting features are not regarded as an integral part of the formal management program but they are considered necessary to provide the support and to create the environment which enhance the chances of the program's success.

This chapter discusses the supporting features of a maintenance management program which include, attitude to maintenance, maintenance objectives, maintenance policies, total life-cycle maintenance, the maintenance annual report, and the maintenance management manual.

2.1 Attitude to Maintenance

Historically, maintenance has been considered as an "after-the-fact" activity, receiving attention only when the desired equipment (or plant) does not perform as intended; and has received top management only when there is an immediate serious problem and the atmosphere borders on a crisis. (11)

Today, the situation remains the same in many mining operations. Maintenance exists in a negative atmosphere, receives virtually zero recognition and more often than not, is relegated to the bottom of the organizational structure. (59) What sort of effect does this attitude have on maintenance and its management program? This will vary, of course, with the operation and the personnel but, generally, it is adverse. The following are some of the effects of the above attitude: (60,84)

(a) Maintenance receives virtually no co-operation from the other functions. It becomes generally regarded as a tolerated activity, justified only by the turnover of business.

(b) Maintenance workers and their supervisors feel inferior to their production counterparts. They question the importance of their work, lose pride in their efforts and eventually become frustrated.

(c) Maintenance is regarded as subordinate to production. All its requirements, therefore, become secondary to those of the production area.

(d) The maintenance department becomes the company "dumping ground." Production supervision, especially front line supervisors, dump all problems into the lap of maintenance.

It is important to realize that maintenance is not an isolated function - it cannot function effectively on its own. The effectiveness of maintenance service depends on sound interaction with the main participating departments namely: production, stores, purchasing, accounting and personnel. Since each of these will have a particular point of view, it is up to top management to set the example by adopting a positive attitude and giving its full support to the maintenance function. Depending on management's attitude, maintenance may be able to attract the co-operation of the other functions, obtain more technical assistance and generally receive the recognition of all other areas of the operation. (84)

Some basic attitudinal guidelines for the maintenance function are as follows: (84)

(a) Maintenance should be regarded as an intrinsic part of existence-and-operation. Instead of being given grudging acceptance, it should be rightfully recognized for its important role in the success of the overall operation.

(b) Maintenance should not be made to feel responsible to production. It should be accepted as a primary function which cannot be managed as a part-time activity.

(c) The maintenance manager should report to as high an authority as is feasible. He is the person most suitable to sell maintenance to the rest of the organization.

(d) The head of the maintenance department should have as much authority as possible since the standing of the department is greatly enhanced by the status of its boss. The more authority he commands, the more favourable the effect on his team.

(e) A positive attitude to maintenance should start at the top of the organization - executive level. The example set at this level will be reflected by all other levels and will, to a great extent, dictate the overall seriousness with which maintenance is viewed.

2.2 Maintenance Objectives

Very little can be accomplished by individuals or groups within an organization if factions are striving for objectives which are different. (49) It appears desirable therefore, that organizations should endeavour to define their overall (or ultimate) objective and then specify sub or lower-level objectives which take into account external influencing factors. Maintenance objectives fall into this lower-level grouping.

The objectives of a maintenance service are dictated by the nature of the enterprise and they vary widely in a mining operation, for example, the overall objective of maintenance is usually to minimize the maintenance cost-component per tonne of ore. However, to realize this primary goal, many other secondary objectives must be achieved. Therefore, in order to know how to proceed, the objectives of maintenance must all be defined in clear terms.

In practice, it is usually assumed that the objectives of the maintenance function are clear and self-evident. (84) However, a wide gap often exists between what management and maintenance believe to be the objectives of the maintenance function. Other views may be held by production and other personnel in the organization. Therefore, it is advisable to spell out the objectives of maintenance in clear terms and have them made known to everyone involved.

Cost objectives and operational objectives are the two main areas that need definition (see Table 2.1). The realization that these two groups of objectives differ explains why management and maintenance are often at loggerheads and why two apparently conflicting attitudes exist: management is always demanding better results for less money while maintenance claims that available funds are too little. The only way out of this conflict is to clearly define the expected results and the means by which they should be achieved.

Before deciding on a specific set of maintenance objectives, an assessment should be made of the overall needs of the operation. Such an assessment will better equip management to select those objectives particular to its situation. The use of a checklist, by all levels of maintenance management, as shown in Table 2.1, can be of great assistance. Discussion of these objectives can assist in determining which are compatible and workable and, when clearly understood, will certainly pave the way to a mutual understanding between management and maintenance.

Maintenance affects company profitability through its influence on availability (plant output) and through the cost of the maintenance resources thus used. (57) Although this is clear, it is still difficult to generalize about the

Table 2.1 A Checklist of Maintenance Objectives (84)

Which of the following objectives apply to your operation	Yes	No	Remarks
Operational Objectives:			
1. To maintain equipment (a) in top operating condition			
(b) in acceptable condition			
2. To ensure maximum availability for plant and equipment at reasonable cost			
3. To provide service that will avert breakdown at all times and at any cost			
4. To extend plant life to the last limit			
5. To maintain plant and equipment with maximum economy and to replace at predetermined periods			
6. To ensure high-quality performance			
7. To ensure safe and efficient operation at all times			
8. To maximize output over a given period			
9. To maintain a reasonable appearance of plant and equipment			
10. To maintain plant and equipment spotlessly clean at all times			
Cost Objectives:			
1. To minimize maintenance expenditure and to maximize profits			
2. To provide maintenance service within the limits of a budgeted amount			
3. To have maintenance expenditure on the amount of service required by plant and equipment in view of age and utilization			
4. To allow a certain amount of contingencies at the discretion of the maintenance management			

maintenance objective since it will be expressed differently for different operations. However, what can be stated is that the maintenance objective is closely linked to the production plan.

Essentially, the maintenance objective is to provide production with long- and short-term equipment availability requirements at minimum cost. In this regard, it is essential for an operation to state its maintenance objectives and even more essential for production to co-operate closely with maintenance in setting long term availability requirements of equipment. Too often, production reacts to market demand by over-working equipment to achieve high availabilities. (57) In the long term this can be very expensive since the condition of equipment deteriorates due to lack of maintenance. Therefore, it should be ensured that maintenance objectives are discussed with, and agreed upon by both the maintenance and production personnel.

It must be emphasized that management by objectives applies to maintenance just as much as it applies to production or any other function within an organization. Moreover, it is important that clear-cut maintenance objectives be established since it is in line with these that the maintenance management program will be developed.

With the passage of time, the objectives of an organization may change. How to deal with such an issue is, of course, management's task. However, maintenance must be considered in any revision of objectives. It must both be kept informed and be allowed to have a say in the setting of a revised set of objectives.

2.3 Maintenance Policies

Policies are the governing principles, plans or course of actions followed by the maintenance department to achieve a sound and effective maintenance program. They provide guidelines which assist in achieving the defined objectives of the maintenance function and indicate steps to be followed to cope with situations as they arise.

A study (84) conducted by the American Management Association has shown that maintenance policies are rarely defined and very rarely exist in written form. To quote a research report of the Association, "Control of Maintenance Costs."

> "Maintenance policies have usually evolved from experience in a rather haphazard fashion rather than being designed to implement specific maintenance objectives. Relatively few of the companies have written maintenance policies. Existing largely in the minds of maintenance supervisors, uniformity and continuity in policies tend to be lacking. In part, this situation is attributable to lack of management attention to maintenance."

Essentially, maintenance policies should be clearly defined and made available, in written form, to all personnel connected with the function. They should include provisions for accomplishing all the responsibilities assigned to the maintenance department. The advantage of defining and using policies is that management can convey its intention to all ranks so that everyone involved knows what is expected of him. (69) In the absence of policies, management has virtually no control over the maintenance operations.

The functions that are expected to be performed by maintenance are not self-evident. Very often, in practice, some functions are only partly stated, some are assumed and others assigned to maintenance because it is considered the "dumping ground." (3) When this is the case, too much extraneous load is carried by the maintenance department and a distorted picture of the operations results. It is only by means of clear policies that management can define what maintenance is actually expected to perform in a given operation.

2.3.1 Operational Policies

Broad policies which relate to the operation of maintenance are usually the responsibility of the top echelon of management. They should be designed to cover the full spectrum of the maintenance operations and to have some inter-relationship with the other functional policies of the company. These policies can be grouped as follows: (84)

(a) Scope and limits of maintenance;
(b) type and level of service required:
(c) limit of maintenance management authority;
(d) budget and financial controls;
(e) maintenance personnel.

Scope and Limits of Maintenance

Policies in this group should determine what is within the terms of reference of maintenance and what is excluded. This is important for the existence of a mutual understanding between management and maintenance.

Moreover, there should be a clear classification of "in-house" maintenance activities. In large operations maintenance activities are quite separate from those of plant engineering. However, in small to medium-sized operations, they may all be classified as maintenance. Apart from the obvious jobs of repair, lubrication, overhauls, inspection and replacement of parts, maintenance may be required to perform such duties as: (57, 60, 84)

- training of production operators;
- testing parts for suitability;
- improvements and modification of plant;
- production of spare parts;
- construction or installation of plant;
- transfers and dismantling of plant.

This policy group is therefore essential for informing and guiding maintenance as to the scope and limit of its activities.

Type and Level of Service Required

This group of policies should reflect the objects of maintenance in the particular operation. They should indicate the amount and intensity of the service that maintenance is expected to provide to meet the needs of production. In fact, they should clearly specify the level, intensity and thoroughness of service expected from maintenance.

The level of service in any operation depends on the balance between the cost incurred and the functional objectives of the company. If cost-saving objectives predominate, the level of service may be restricted. There are, however, two aspects to the level of maintenance service: (a) the performance of equipment and (b) its appearance. The former can be quantified, that is the mechanical condition that determines the quantity and quality of production output, and the degree of trouble-free operation. The latter, though it has effect, is of a lesser importance in mining operations and is merely determined by company policy.

Thus, standards for the level of maintenance for achieving both high performance and good appearance should be clearly laid down by means of policies. These should allow a better interpretation of maintenance results and costs.

Another area that should be covered by this group of policies is that of priorities. Maintenance is often faced with situations where decisions rely on compromises, especially when alternative solutions are available. Selection among alternatives must reflect priorities but priorities cause conflict, therefore, policies should be established to indicate how priorities are assigned when the question arises. Policies relating to priorities should not only refer to urgency but should also include the following: (7,57)

a) amount of time to be spent on certain jobs and equipment;
b) repair versus replacement;
c) routine service versus irregular jobs;
d) simultaneous emergencies.

Limit of Maintenance Management Authority

What is the limit of the authority delegated to maintenance management? Policies should be established to define this limit in the following areas:

a) authorization for expenditure (upper limit)
b) authorization of job requests;
c) authorization of overtime work;

d) taking equipment out of operation;
e) ordering spare or replacement parts;
f) instituting disciplinary measures;
g) emergencies and unforseen contingencies.

Budget and Financial Controls

The primary objective of a maintenance management program is to minimize the cost associated with maintenance. A program must therefore include some form of budget and financial controls.

Policies must be set that enable maintenance to operate within the required limits of expenditure. Provision must be made to take into account the true condition of the equipment and its usage, as well as the purchase of spares, materials and tools for maintenance. These policies should not determine the amounts to be allocated, which will vary, but the limits in the form of operational ratios or other benchmarks. (84) They should also specify the way in which control is to be exercised by management.

Policies relating to the budget should lay down clear procedures to be followed in preparing the document. These procedures should ensure the following: (79)

a) accurately predicted costs of maintenance activities; no historical expenditures with minor adjustments for current conditions;
b) a continuous operation - data is gathered continuously;
c) bench-marks are set at a tight but realistic level.

The fact that personnel will have to work with such a document, forces them to plan and control spending much more than they normally do.

Reporting Procedures

Policies within this group should be designed to achieve the double effect of requiring maintenance to report and at the same time obliging management to take an interest in maintenance. This approach should provide some solutions to the many problems of management's attitude to maintenance.

Policies relating to reporting procedures should deal with the following: (62,68)

(a) contents of reports;
(b) timing and frequency of reporting;
(c) recording procedure to obtain data;
(d) accuracy demanded;
(e) format of reports;
(f) distribution of reports;
(g) controls to be reflected.

Maintenance Personnel

Policies regarding maintenance personnel should deal with the following points: (84)

(a) strength, as related to scale of operation;
(b) selection, training and promotion procedures;
(c) trade skills of craftsmen;
(d) supervisory strength and practices;
(e) wages and salaries, incentives;
(f) safety programs.

2.3.2 Procedural Policies

Once the maintenance management program has been developed and broken down into its various components, definite policies should be established to assure effective maintenance procedures. The development of these policies is usually the responsibility of maintenance, with some input from production. However, prior to final approval, both departments should confer with top management. In developing these policies care should be taken to ensure that they are compatible with the policies of the organization. For example, it would be unsatisfactory for the maintenance department to pursue a policy designed to minimize downtime of equipment if the organization requires a policy to maximize profits. (48) These two policies may be identical but this is not necessarily so. The conference with top management, prior to final approval, should ensure the compatibility desired.

Procedural policies should cover all work activity of the department including: (4)

- preventive maintenance;
- repairs;
- replacement;
- overhaul;
- inspection;
- lubrication;
- fabrication and construction;
- salvage.

Preventive maintenance, for example, requires that equipment be inspected at regular intervals and, depending on the results of the inspection, that repair/replacement of components be made. Such requirements, along with many others are adopted by the maintenance department. Procedural policies should designate how, when and where these requirements would be fulfilled.

In recent years, analytical techniques such as reliability statistics and mathematical modelling have been applied to problem situations in many of the above areas, to assist in determining optimum policies. These techniques and how they are applied are discussed, in some detail, in Chapter 8.

The adoption of adequate maintenance policies provides a kind of operating charter that will serve management, production and maintenance. (84) The establishment of policies requires adequate information regarding equipment or plant and the matching of existing needs with available means. Adopting policies and including them into an "operating manual" will be significant steps towards creating the kind of environment and providing the kind of support, needed for proper functioning of maintenance management.

2.4 Total Life Cycle Maintenance

Total life-cycle maintenance, as presented herein, addresses itself to those activities required throughout the life cycle of equipment or plant to ensure that maintenance requirements are optimized. (11) It involves all the factors, see Figure 2.1, influencing maintenance costs over the equipment life cycle.

The dependence of life-cycle profitability on availability, and hence on maintenance, has greatly increased as equipment/plant has become larger and more sophisticated. Nowhere is this situation more evident than in the mining industry. For example, in the processing section of the industry large single-stream plants have replaced the previous many smaller plants, in search for economy of production. (57) As a result, high plant availability has become vital to life-cycle profitability. This has been demonstrated in a study (56) of processing plants, conducted by the University of Manchester, England, in which it was shown that although other factors cannot be ignored, plant availability levels have by far, the greatest effect on rate of return on investment.

Many other examples (11, 57) show the increasing effect of maintenance costs and unavailability on life-time profitability. Therefore, the question arises as to how these factors can best be controlled. Is it via the so-called "total life-cycle maintenance" approach?

Experience (11) has indicated that a total life-cycle maintenance program, see Figure 2.2, can greatly reduce maintenance cost and improve equipment availability, because of the aspects of equipment or plant development that are considered in such a program. The program ensures that both management-related and technical factors are examined in the early planning and design stages. The program is usually based on good co-operation between users and designers/manufacturers and, more so, a strong liaison between maintenance personnel and engineering designers of equipment. With such liaison, design deficiencies which may subsequently cause costly failures and increase maintenance requirements, can be detected early and corrected.

2.4.1 Why Total Life-Cycle Maintenance?

The bulk of the projected life-cycle cost for equipment or plant is affected by both management and technical decisions made in the early planning and design stages.

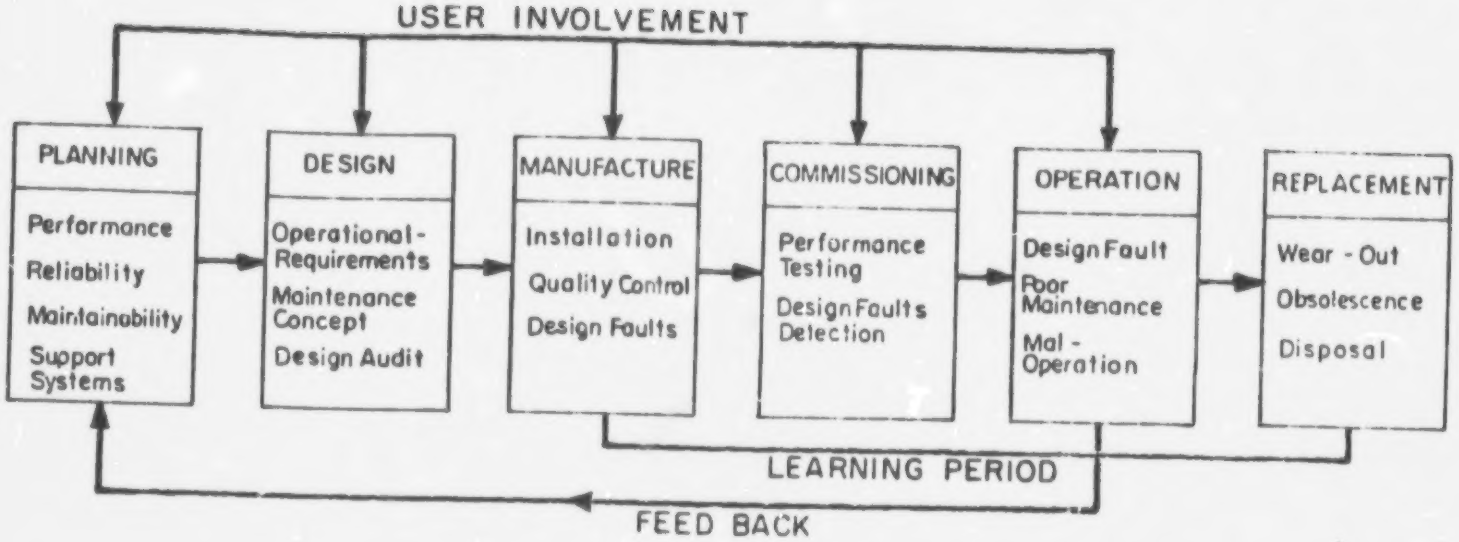

USER INVOLVEMENT
PLANNING
Performance
Reliability
Maintainability
Support Systems
DESIGN
Operational-Requirements
Maintenance Concept
Design Audit
MANUFACTURE
Installation
Quality Control
Design Faults
COMMISSIONING
Performance Testing
Design Faults Detection
OPERATION
Design Fault
Poor Maintenance
Mal - Operation
REPLACEMENT
Wear - Out
Obsolescence
Disposal
LEARNING PERIOD
FEED BACK

Fig. 2.1 Factors influencing maintenance costs over life cycle (57)

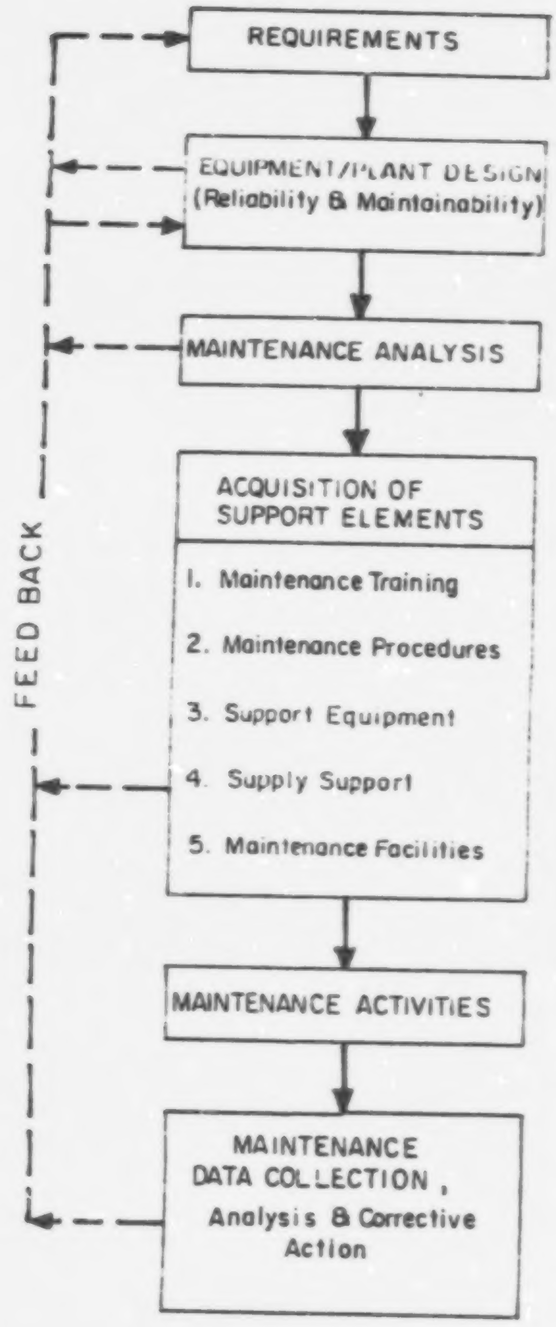

REQUIREMENTS
EQUIPMENT/PLANT DESIGN
(Reliability & Maintainability)
MAINTENANCE ANALYSIS
ACQUISITION OF SUPPORT ELEMENTS
1. Maintenance Training
2. Maintenance Procedures
3. Support Equipment
4. Supply Support
5. Maintenance Facilities
MAINTENANCE ACTIVITIES
MAINTENANCE DATA COLLECTION, Analysis & Corrective Action
FEED BACK

Fig. 2.2 Sequence of activities in total life-cycle maintenance (11)

Therefore, the costs of maintenance and its support can be significantly influenced by actions taken at these stages. For example, high maintenance costs can be directly attributed to the following: (11)

(a) Inadequate planning of how equipment/plant is to be maintained after it has been developed and produced (ie. the lack of a defined maintenance concept).

(b) Inadequate consideration of the proper level of reliability in the design, which, in turn, influences the frequency of maintenance and the logistic support required for such maintenance.

(c) Lack of design for maintainability. With much of the large-scale equipment currently in use, many problems occur which actually inhibit their effectiveness on a day-to-day basis. Some typical problems are:

1. complexity involved in job accomplishment
2. difficulties posed for maintenance personnel: difficulty of fault detection, verification and diagnosis; inaccessibility of items requiring maintenance.

(d) Inadequate design of logistic support capability. For example, maintenance activities are often hindered by not having:

1. the right type and/or quality of spares available at the time and place of need
2. the proper tool and test equipment
3. adequate data and/or instructions
4. adequate facilities.

In essence, maintenance costs are directly affected by not only the design of primary units (eg. trucks, shovels, processing plant), but also the design of logistic support. (11) Logistic support includes supply support (spare parts, inventories), tools and other maintenance facilities.

Basically, maintenance has an impact on a significant portion of life-cycle activities. Therefore, during the planning and design of equipment the maintenance activities in all phases of the life cycle must be addressed. If operations are to reduce overall maintenance costs and better allocate resources, then total life-cycle maintenance management is essential.

2.4.2 Maintenance Considerations in the Equipment/Plant Life Cycle

Figure 2.1 illustrates the overall equipment/plant life-cycle and the various activities that pertain to maintenance, one way or another. Although the figure refers to the development of new systems, it is also directly applicable to the evaluation and modification of existing systems. The figure is intended to illustrate an overall "evolutionary process" and as presented, should be tailored to the particular problem on hand.

Planning for Maintenance

This must begin from the inception of the program and should include a combination of technical feasibility studies, operational analyses and advance equipment/plant planning. Moreover, both maintenance and operating personnel should have the means to have major inputs into the program at this stage.

Planning for maintenance should evolve from a definition of operational requirement and the basic maintenance concept. Information of interest at this stage includes the following: (18, 57)

(a) Definition of Operational Requirement:

1. How is the equipment or plant to be used? What is its primary (and secondary) mission? What is the mission profile?
2. What are the operating characteristics of the equipment and the specific functions that it has to undertake?
3. How will the equipment be deployed? What is

the expected operating life?

4. What are the required effectiveness characteristics (readiness, availability, reliability and maintainability)?
5. What is the anticipated working environment?

(b) Definition of the Maintenance and Support Concept:

1. What are the anticipated levels of maintenance and support (eg. on-site or organizational)?
2. What basic functions are to be accomplished at each level of maintenance? What support is required at each level (eg. tools, spares, personnel)?
3. What are the required support effectiveness characteristics (eg. availability and reliability of material, probabilty of spares availability, supply time)?
4. Where and in what environment is maintenance to be done? What facilities are required and where are they to be located?
5. Who is responsible for the accomplishment of maintenance and for what period of time?

Although the above questions are rather basic in nature, it is not uncommon to proceed with equipment/plant design without giving them due consideration. The objectives at this stage are:

1. to create an awareness of maintenance and its support requirements as early as possible
2. to identify the desired results relative to equipment performance, use and support
3. to establish the necessary criteria for equipment design with the goal of maximum performance in mind
4. to initiate the necessary planning to enure that these objectives are met.

With this kind of information at hand, and in close co-operation with manufacturers/designers, an operation can better evaluate alternatives (on the basis of life-cycle cost and other related factors) and thus improve the decision-making process.

Maintenance Considerations at the Design Stage

Major equipment design characteristics that will significantly influence maintenance will do so both qualitatively and quantitatively as part of the defined operational requirements and the maintenance concept. (18)

At the design stage, reliability and maintainability are the important factors and must be considered in relation to equipment performance, capital cost and running cost. (11) In the past, far too much emphasis has been put on performance and capital cost at the expense of reliability and maintainability. (11) In this respect the "method of production" is particularly important. For example, if it is decided to process a mineral by a continuous rather than a batch process, then careful consideration should be given to the much higher maintenance costs that inevitably occur.

Reliability and maintainability parameters such as Mean Time Between Maintenance (MTBM) and Mean Time Between Failure (MTBF), provide maintenance frequency and repair time targets. (18) Factors such as supply time, total downtime, spare part response time and organizational effectiveness, influence the logistic support capability. (18) Qualitative design features such as accessibility, diagnostic and condition monitoring provisions, standardization, modularization, interchangeability and safety, are also prime considerations. (11, 18) These and other characteristics, translated from qualitative and quantitative requirements into specific features, are of prime importance during the design stage.

Significant activities during equipment design and development should include: (11, 18, 57)

(a) Allocation of requirements

Given overall design requirements for the equipment, it is necessary to allocate these requirements to the appropriate subsystem levels so as to influence the design in terms of the desired maintenance and support features.

(b) Maintenance Analysis

This is an interactive ongoing analysis for assessing the design in terms of supportability and identifying the logistic support requirements.

(c) Design review and evaluation

The result of the maintenance analysis must be included as part of a routine program design, review and evaluation, thus ensuring that the allocated design requirements have been met. In areas of non-compliance, corrective action can be initiated.

Maintenance Considerations at the Manufacturing-Commissioning Stage

Clearly, quality control during equipment manufacture will strongly affect the subsequent level of maintenance. Quality considerations must be given to identifiable items and components, based on information provided by the users, both maintenance and operating personnel. Also at this stage, maintainability must continue to be an important consideration because it is only then that the multi-dimensional nature of many of the maintenance problems become clear. (57)

The commissioning stage is not only a period of technical performance testing but also a learning period, where primary design faults that might affect equipment availability are located and designed out. Failure to do this will, in effect, mean serious maintenance problems and high unavailability early in the operational life. The same effect will occur if the equipment is operated past its useful life period and into the replacement period.

2.4.3 Maintenance Management Role

It is clear from the foregoing that the best time to influence maintenance and unavailability costs is before the equipment or plant comes into use. It is essential that management appreciates this and provides the necessary resources to create systems to ensure that equipment, when handed over to production, not only performs its function but is reliable and easily maintainable. In this respect the following points must be emphasized: (11)

(a) Maintenance-operating personnel should co-operate with the equipment-manufacturer in a comprehensive analysis of equipment's reliability, maintainability and safety characteristics. Such an exercise should include assessment of spare part provisioning, of maintenance personnel training, and supplier support systems. The higher the potential costs of maintenance and unavailability the more vital is this exercise.

(b) Decisions to buy new or replacement equipment should be based on a present value life-cycle analysis of costs. Such an analysis must take into consideration the estimated or historic maintenance and unavailability costs.

(c) Maintenance personnel and the supplier should cooperate in the collection and analysis of equipment failure and maintenance data in order to identify maintenance problem areas and to determine the equipment's optimum maintenance operation. Since the design of equipment is a continuing process, information thus gathered should be continuously fed back to the equipment manufacturers.

Failure on the part of the organization to appreciate these fundamental ideas will mean that the maintenance manager is likely to be wasting his time on unnecessary maintenance when equipment comes into operation.

During the operational life of equipment the maintenance manager's task is two-fold: the determination of the best maintenance policy; and the organization and control of men, spares and tools to carry out this policy. These aspects will be considered, in more detail, in later chapters of this thesis.

2.5 Maintenance Annual Report

Traditionally, all funds spent for maintenance have been in the expense category. (69) This arrangement does not allow management to judge the ability of maintenance to program improvements. Further, it does not give maintenance an opportunity to participate in capital programs that will increase its productivity.

Maintenance should have its own annual report. A comprehensive report, designed to indicate the manner in which maintenance management is utilizing its resources. It should be the main communication link between top management and the maintenance department and should cover the following: (69)

(a) Intermediate and long-range plans;
(b) Contract versus in-plant maintenance;
(c) Capital investment programs;
(d) Cost evaluation;
(e) Performance evaluation.

Intermediate and long-range plans

These should be broken down into manpower, equipment and material resources. Manpower should include craftsmen, broken down into craft categories and administrators such as maintenance planners, schedulers, and other methods analysts. The need for equipment should be presented so that it can be integrated into the company's capital investment program. Materials should be reported in terms of the dollar value of spares carried in stock and should be categorized to emphasize high-cost items, critical items and items with long delivery times.

Necessary to any long-range planning for maintenance is the integration of technological forcasting. The forecast criteria used should be derived from the most up-to-date information possible so that the latest projections are included in the annual report. Long-range plans should include a forecast of increased or decreased maintenance productivity, effects of training programs, considerations of contract maintenance, and the effects of large-scale technological developments, such as computer control, that might have a significant impact upon maintenance requirements.

Contract versus in-plant maintenance

Contract maintenance can mean different things to different people. In this text it is defined as: "The delegation to an outside organization of the responsibility for maintenance in full or in part, while retaining full control over expenditure, quality and quantity". (65)

In many maintenance situations, the use of contract maintenance to supplement in-plant forces is becoming an increasing attractive alternative. This is particularly true for many mining operations in the U.K. where a shortage of skilled craftsmen seriously affects maintenance performance.

While the use of contract maintenance may not be practical/economical in small remote operations, it is certainly a feasible alternative for larger operations, especially in areas where a shortage of skilled labour is evident.

When used by maintenance, the status of contract maintenance should be included as a part of the annual report. Information should include the extent of its use, the specific activities for which it is employed and a comparison with in-plant maintenance in the areas of cost, quality of work and performance.

Capital Investment Programs

Maintenance management must also have a plan concerned with capital programs, intended to improve the ability of maintenance to perform the work required of it. The capital investment programs considered in the annual report should include not only capital equipment, but also participation in training programs and any other capital projects that would have an effect upon maintenance performance. These programs are usually accomplished over a long time period and an appropriate portion of them should be included in each annual report.

Maintenance should justify these programs by demonstrating a percent return on investment. This is a familiar approach and program proposals that are presented in this manner are more likely to receive apporpriate consideration.

Cost Evaluation

Since the control aspect of the budget is an all-important part of maintenance management, budget variances, pin-pointing areas where expenditures are out of control, should be integrated into the annual report. Variance reports should list projects or categories of expenditures which are greater than or less than some percentage range which is established by management. Reasons for variances which exceed established bench-marks should also be provided.

Other cost indicators could include percent of direct maintenance cost to total labour cost, percent of indirect maintenance cost to total maintenance cost, percent of maintenance payroll, percent of overtime, and administrative cost as a percentage of total maintenance cost.

Performance Evaluation

The "bottom line" of any maintenance annual report must be a quantitative assessment of how well maintenance is performing. Maintenance performance should be divided into two classes; labour productivity - indicates how well the maintenance crews perform their jobs - and maintenance control - indicates how well maintenance management, planning and scheduling perform their tasks.

The most commonly used labour productivity indexes compare a pre-determined "standard" time for work orders to the actual time spent on those work orders. Other performance control indexes could include any or all of the following: (68)

(a) Work-load indicators: current backlog of work, total backlog, manhours spent on planned maintenance, and the number of open work orders;

(b) Planning indicators: jobs completed on schedule, scheduling effectiveness, planned hours versus actual hours worked, emergency work, overtime, and downtime;

(c) Performance indicators: maintenance manpower effectiveness.

The maintenance annual report should not only inform management of how well maintenance is doing its job; it should also serve to inform maintenance itself of the areas of strength and weakness in the program. The very fact that an annual report is prepared would indicate to management that maintenance does plan and that requested capital funds are part of a long-range comprehensive program.

2.6 The Maintenance Management Manual (69)

A significant degree of support is provided to the maintenance operations if its management program is documented in the form of a manual. Reducing the management program to writing, provides continuity and should lead to a better understanding of the program, enabling corrections to be made early in its life. The maintenance management manual should include such topics as narrative descriptions, flow sheets, sample forms, job descriptions, measurement programs, control indexes and annual report format.

The manual should be distributed or made easily available to everyone connected with the program; this includes personnel in the stores, purchasing, accounting and operating departments. It should answer procedural questions related to such matters as work orders, time cards, material lists and the many other problems normally encountered in the day-to-day maintenance operations.

The manual should commence with a brief narrative description of the purpose and workings of the maintenance management program. It should next include a flow sheet showing the work forms, the way in which information is recorded, and the uses to which that information is put. The flow sheet should also indicate the eventual disposition of the various copies of forms. Job descriptions should be an integral part of the manual. These should be used to convey to the various personnel the limits and responsibilities of their positions.

A sample of all forms that are necessary for the program should be included in the manual together with instructions for completing each form. How and why each form is used should also be explained.

An important part of the manual should be a description of the various programs used to monitor, control and improve maintenance productivity. These programs could include work sampling, assessment indexes, training programs and methods, and a continual review of maintenance operations from the standpoint of minimizing costs.

If the organization uses contract maintenance, the information necessary to decide whether or not to contract work should be included in the manual. The various indexes and the format for the annual report should also be included.

2.7 Conclusion

The supporting features described in this chapter are essential in any maintenance management program. The extent to which each is applied will vary from program to program, depending most of all on the size of the operation and the degree of mechanization. However, each feature plays a part in ensuring that the entire maintenance program is conducted in an environment where it is a key element to the production activity.

Management's attitude to maintenance is of primary importance. In all cases, this determines the seriousness with which maintenance is viewed and influences, to a great extent, the chances of the program's success.

Maintenance objectives and policies constitute the framework within which the maintenance management program is developed. They provide direction to the maintenance department and spell out how the various functions must interact with maintenance.

Both the annual report and the maintenance management manual are communication links, providing channels for the flow of information, within the maintenance department and the organization as a whole.

The total life-cycle concept provides the means of viewing maintenance in a wider context. This approach has two inherent advantages, one directed towards improved equipment design, and the other towards finding new maintenance management tools.

All together, the supporting features provide the foundation on which the essential features of a maintenance management program can be formulated and developed.

Chapter 3

MAINTENANCE ORGANIZATION

The effectiveness of maintenance management depends, to a large extent, on the suitability of the maintenance organization in place. Organization is the primary, essential element of a formal maintenance management program. Proper performance of the maintenance function can only be assured if it is based on an effective organization with logically delegated authority, hand-in-hand with clearly defined responsibilities.

There is no single set of rules that can be applied in organizing maintenance. In fact, there is no one best maintenance organization that can be used in all cases. (90) However, adherence to certain basic principles is essential.

Maintenance organization should be tailored to meet the particular technical, geographic and personnel situation involved. As a result, each organization must reflect size of operation, location, type of equipment, type of work done and other relevant factors applicable to the particular operation. A good maintenance organization should also display the best in management practice, engineering judgement, plus proper distribution of responsibility and authority. (29)

Deciding upon either a centralized or decentralized maintenance organization brings a number of important factors into play. Moreover, many of these factors are interrelated. The pros and cons of each factor must be considered for the particular operation involved. The result is often a variation or combination of the centralized and area concepts. (90) However, the organizational structure, be it centralized or decentralized, is only part of an efficiently operating maintenance team. There must also be adequate policies, procedures and repeated training of personnel in how to function as team.

Organizing maintenance in mining operations is always a big challenge. The geographic layout of many mine sites tend to "thin out" supervision and maintenance personnel. (85) The variation in mining methods and scattered location of equipment, further contribute to the problem. (85) In the final analysis, the organization should be structured to ensure optimum production maintenance contact and strong lines of communication throughout the operation.

Guidelines as to what factors should be given consideration, in developing maintenance organization, are offered in this chapter.

3.1 Maintenance Within Overall Company Structure

The development of an efficient maintenance organization requires the combined efforts of all parties concerned and particularly, the support and understanding of top management.

Achieving the optimum in maintenance performance is directly linked to the position that maintenance holds within the overall company structure. In the proper position, maintenance is better able to develop the kind of cooperation with production, stores and accounting that is essencial to proper functioning of its management program.

In view of the above, certain organizational factors must be recognized and clearly understood. The following are some basic orgainzational guidelines: (84)

(a) An organization chart should be developed to assist in establishing the position of maintenance in relation to the other functions in the company. There is no universal organizational chart which can fit all situations, the final sturcture adopted must be left to the discretion of management.

(b) All activities relating to maintenance should be managed by one authority. The head of the maintenance department should be responsible for the entire maintenance function.

(c) Maintenance should not be combined with or be responsible to production. It is a primary function that cannot be managed as a part-time activity.

(d) Maintenance should have representation at the decision-making level of the organization. In this way it can participate in the policy-making process of the enterprise.

(e) Maintenance stores should be the direct responsibility of the maintenance manager. In this way, if spares or materials occasionally run out, he has no one to blame but himself.

(f) Maintenance stores should have a strong interface with purchasing to ensure expediency in the ordering of spares.

(g) Overall company structure should facilitate optimum cooperation between maintenance and production personnel. For example, maintenance and production department heads should report to a common authority.

The above guidelines should apply well in most situations, however, in the event of an exception, it is top management's responsibility to ensure that maintenance occupies its rightful position within the overall company structure; a necessity for optimizing both the service provided and the performance of the maintenance management program.

3.2 Structure of the Maintenance Department

The internal structure of the maintenance department also has a significant effect on maintenance service and the performance of the maintenance management program.

At one time mining operations could choose from a number of maintenance organizational configurations, depending on specific needs. Today, however, with larger operations and the consequent complicating factors, the choice is very much restricted. There are basically three organizational configurations that are suitable for adoption in the mine maintenance department: area organization, central organization and central-area organization (sometimes termed a combination plan).

3.2.1 Area Organization

This configuration makes a single foreman responsible for all maintenance carried out in a well defined, reasonably sized area. The area may be defined geographically, by production grouping and/or by service function. (90) The area foreman usually has a multicraft crew that performs a limited amount of on-site maintenance including preventive maintenance inspections, routine jobs, minor emergency repairs and small unscheduled jobs. (90) In the event of major repairs or servicing jobs this type of organization has to request additional support from the centrally controlled workshop.

Today, a "pure" area organization is rarely adopted by mine maintenance departments. When adopted, it is restricted to small operations or plants harassed by frequent breakdowns. (90) In such cases, production personnel demand full control of the craftmen assigned to their area and often a switch of control from maintenance to production results.

Although the area configuration has the major advantage of allowing craftmen to be readily accessible to production personnel, thereby reducing time spent travelling and simplifying job scheduling, its restricted use in large maintenance departments is primarily because of the following: (69, 102)

- proper area staffing is a major problem; there is a tendency to overstaff the area;
- major repairs and servicing jobs are difficult to handle;
- there is a need to duplicate service equipment, tools and shop activities;
- the maintenance department does not have the best control of its work force.

3.2.2 Central Organization

Mine maintenance can, in some instances, effectively use a centrally controlled type of maintenance organization.

In this organizational configuration all maintenance support is requested through a control centre. As service requests are processed and work is assigned, men are dispatched singly or in groups to the different areas. Work is usually planned and scheduled and crews with supervisors are then assigned to different jobs for the duration of the work involved.

Each work request must be carefully analyzed to determine the work content, manpower requirement and duration of the job. In this regard, the planning and scheduling function must be given a prominent position in the organization to keep pace with the volume of requests and to ensure optimum distribution of the available workforce.

A number of operations have found it helpful to switch from a central to an area organization for periods of annual or semiannual shutdown or turnaround. Because plant and equipment do not operate as production units during these periods, routine maintenance is unnecessary, and emergencies do not arise.

The centrally controlled organization is generally suited to small and medium-sized maintenance departments, employing between 50-200 workers. (69) The concensus about the advantages of this configuration includes: (69)

- more efficient utilization of available manpower;
- better control of workforce by maintenance department;
- considerable flexibility in assigning crews to different jobs;
- speedy handling of emergency jobs.

The Algoma's MacLeod mine (19) at Wawa, Ontario is one example of a mining operation that employs a centrally controlled maintenance organization. Prior to 1963 this operation employed 139 maintenance personnel and used an area organization in its maintenance department. The present configuration is the result of a consultant's study of the maintenance operations which recommended the adoption of a centrally controlled organization to improve maintenance effectiveness. Some of the improvements in overall maintenance performance have been attributed to the adoption of the central configuration.

3.2.3 Central-Area Organization

Recently, use of a centrally controlled craft pool in conjunction with the area organization has beeh shown (63) to further improve labour utilization in maintenance departments.

The craft pool helps to minimize the size of area crews since it offers the capability of reinforcing area crews to meet the demand of peak workloads. Once the peak demand has been satisfied, the craft pool members can be withdrawn and assigned elsewhere to meet other peak workloads.

A number of mining operations have adopted this organizational concept and one such example is the Quebec Iron and Titanium Corporation (15), Tracy, Quebec. The organizational structure of the maintenance department (see Figure 3.1) is based on an area concept supported by a centrally controlled craft pool, which contains approximately 10% of the maintenance workforce.

This structure gives the area foremen complete responsibility for equipment availability, preventive maintenance, repairs and cost performance. These foremen are also placed in the position of having to work closely with production counterparts and thus, to appreciate production demands on equipment.

At Quebec Iron and Titanium Corporation (15), it was found that, with the central-area organizational structure, foremen became very creative, cost-conscious and self-motivated. It was also reported that labour productivity increased as a result of re-organizing the maintenance department along the central-area maintenance concept and the implementation of work programs.

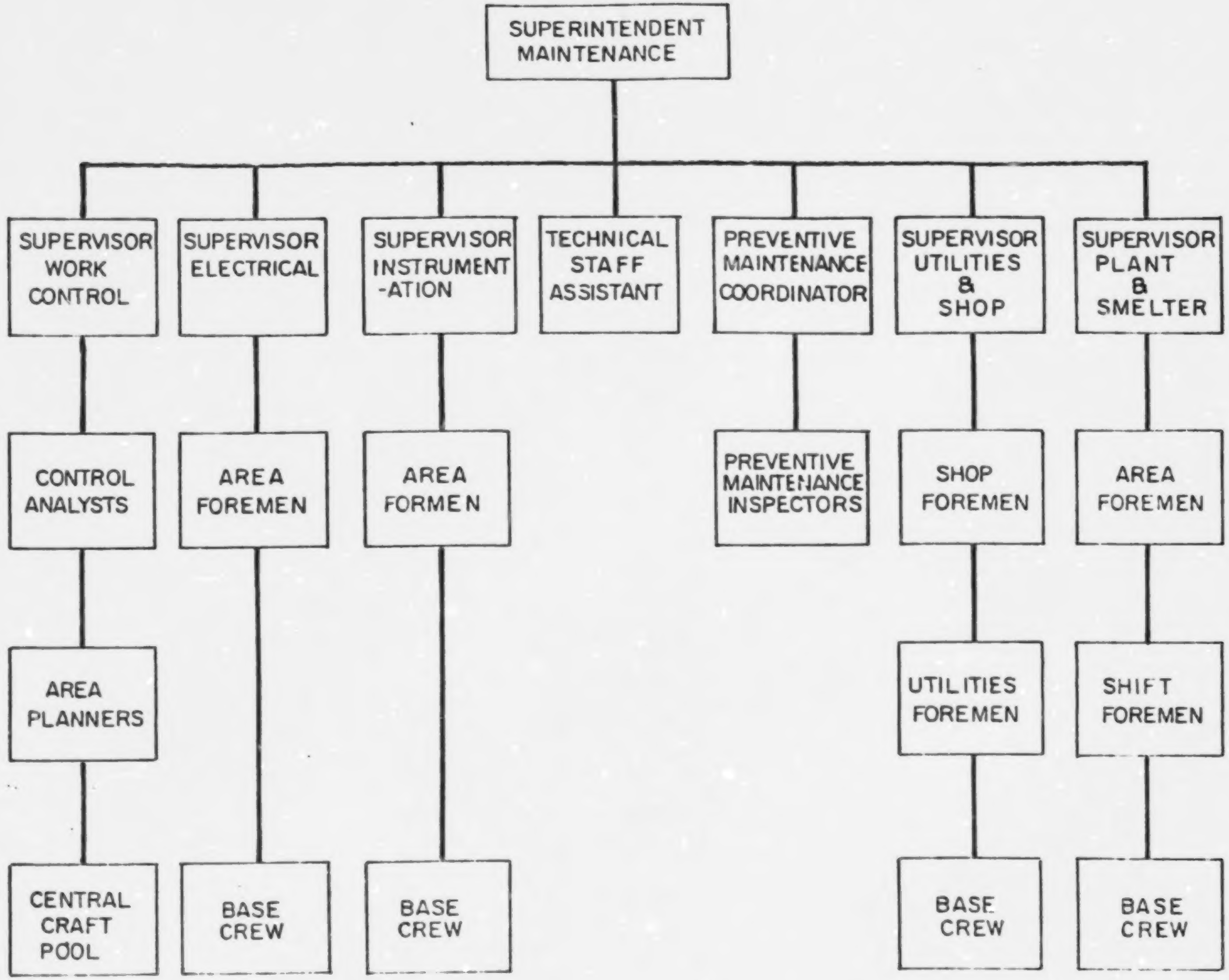

SUPERINTENDENT MAINTENANCE
SUPERVISOR WORK CONTROL
SUPERVISOR ELECTRICAL
SUPERVISOR INSTRUMENT -ATION
TECHNICAL STAFF ASSISTANT
PREVENTIVE MAINTENANCE COORDINATOR
SUPERVISOR UTILITIES & SHOP
SUPERVISOR PLANT & SMELTER
CONTROL ANALYSTS
AREA FOREMEN
AREA FORMEN
PREVENTIVE MAINTENANCE INSPECTORS
SHOP FOREMEN
AREA FOREMEN
AREA PLANNERS
UTILITIES FOREMEN
SHIFT FOREMEN
CENTRAL CRAFT POOL
BASE CREW
BASE CREW
BASE CREW
BASE CREW

Fig. 3.1 Central-area maintenance organization (15)

3.2.4 Which Organizational Concept?

Small departments generally employ a central organizational concept. Large departments with several different service functions most often use a combination plan. However, there is no magic formula for the selection of the best organizational concept for the maintenance department.

Prior to the development of an organization or to any contemplated change, all essential factors must be carefully evaluated. The significance of each factor will vary from department to department. The important point is to recognize that each has an effect upon selection of the maintenance organization.

The three major maintenance organizations are rated in Table 3.1. These evaluations are based on the experience of a consultant (63) who has a long association with industrial maintenance management. The individual control performance factors are much more important in making judgements than the overall totals.

3.3 Staffing the Maintenance Department

The nature and level of staffing are critical factors in organizing the maintenance department for optimum effectiveness. Staffing refers to the supervisory and administrative personnel of the management program and does not include the skilled and unskilled workers; the latter group is discussed under manpower requirements.

3.3.1 Supervisory Groups

In most maintenance situations the traditional staff positions of manager, superintendent and supervisor are well established. Therefore, apart from emphasizing the important roles they must play in relation to managing maintenance, little mention is made of these staff positions in this section. However, because of the recent trend in maintenance management, the positions of engineer and foreman require a brief review.

The maintenance engineer has a vital role to play in

Table 3.1 Comparison of Maintenance Organizations (63)

Ratings:
1 - 3 Poor
4 - 6 Good
7 - 10 Excellent

Control/Performance Factors	Central Organization	Area Organization	Area Organization With Craft Pool
Non-duplication of facilities	10	4	6
Control	10	7	8
Response to production	6	10	10
Use of travel time	2	9	10
Response to supervisor	6	8	9
Utilization of labour	3	8	10
Material control	7	5	5
Planning	8	7	8
Coordination with production	7	9	10
Record-keeping	9	7	7
Positive communication	9	7	7
Work assignment	7	7	8
PM capabilities	8	7	7
Coordination with engineering	10	6	7
TOTALS	102	101	112

today's maintenance environment. He is the person that should be capable of handling the analytical approach that is becoming so necessary for successful maintenance management. (49) He should be able to function at all levels within the department and should play more of an advisory rather than a supervisory role. The key duties of the maintenance engineer are summarized in Table 3.2.

The maintenance foreman is the corner stone of the maintenance organization. (55) He is essentially the frontline leader of the maintenance crew. He should ensure that the organization's policies, programs and schedules are executed in the prescribed ways. The foreman must ensure quality of work, issue instructions, co-ordinate jobs and minimize idle time. The maintenance foreman is far too important to spend his time writing requisitions, looking for spares and doing elementary administrative chores. The maintenance management program should ensure that the foreman's paperwork is so reduced that he spends his time in supervisory work and solving technical as well as, "people" problems. The key duties of the maintenance foreman are listed in Table 3.3.

3.3.2 Administrative Group

Apart from the supervisory group, today's maintenance department must have another group of staff personnel playing an administrative rather than a supervisory role. This group is referred to as the "work control group" (5) or sometimes as the "control unit" (19).

The work control group should be manned by analysts, including planners, schedulers/dispatchers, expediters, a preventive maintenance co-ordinator, technical staff assistants and a cost analyst. The group must be headed by a maintenance control supervisor whose basic function is to direct the activities of the control unit, the work order sytem, application of standards, the planning and scheduling of all service and repairs, analyzing and evaluating the program and the clerical record-keeping systems.

Each group of analysts must work in close co-operation with the other but they all have separate responsibilities to the program.

(a) Planners - establish the job scope and recommend priority; prepare material lists; establish craft requirements and estimate time data through the use of standards; estimate job cost; complete the work order and ensure its transmittal through the system.

(b) Schedulers - accept and schedule all jobs; assign scheduled jobs to different supervisors; hold weekly scheduling meetings; monitor work backlog.

(c) Expediters - ensure the availability of materials and spares in the stores; make materials and spares available when needed, at the job site, before starting.

(d) PM Co-ordinator - audit and update PM checksheets and routes; head a team of PM inspectors responsible for such activities as vibration analysis, non-destructive testing and preventive inspection.

(e) Technical Staff Assistants - provide corrective maintenance and technical problem-solving in the field to aid foremen.

(f) Cost Analyst - generate, record and monitor all relevant cost data; assist in the preparation of the budget.

It is important that the "control unit" be well organized and staffed to provide adequate coverage for every aspect of the management program. Moreover, for optimum effectiveness, it must be structured along the lines of the maintenance department: (85)

Table 3.2 Key Duties of Maintenance Engineer (55)

- Assist in the planning and development of the preventive maintenance program
- Review inspection routines and upgrade check sheets as required; review and optimize inspection frequencies
- Review equipment failure reports; analyze causes of failures; recommend procedures for reducing repetitive and/or costly failures
- Develop and implement a condition-monitoring program for critical equipment; develop defect limits
- Develop and implement analytical procedures to aid in the determination of optimal maintenance policies
- Inspect plant and equipment during mill or mine shutdowns with the aim of improving existing repairs and replacement practices
- Keep up-to-date records of performance trends; analyze date; recommend and initiate remedial action when necessary
- Keep current on the new proven maintenance methods, materials, and equipment; recommend changes or trials as indicated
- Collect necessary data and participate in the preparation of the maintenance budget
- Take active part in cost-saving, safety, and training programs.

Table 3.3 Key Duties of Maintenance Foreman (55)

- Motivate crew members
- Evaluate skills available
- Determine skill required to perform jobs
- Assign crew members to different jobs
- Establish job scope and recommend job priority
- Establish job plan with planner
- Coordinate field jobs and follow-up
- Emergency planning
- Daily scheduling of small jobs
- Ensure safety of crew members
- Quality control
- Methods improvement and general cost reduction
- Identification of causes of failure
- Ensure continuous on-the-job training

- totally centralized "control unit" for a centrally controlled maintenance department;
- area "control units" for an area organized department;
- central plus area "control units" for a department structured along the central-area configuration.

The structure and size (number of personnel) of the "control unit" should always be compatible with the particular maintenance organization.

3.4 Maintenance Manpower Requirement

Maintenance has and will continue to be a very labour intensive industrial function. In many industries, the ratio of maintenance craftmen to production workers is steadily increasing as additional labour-saving production equipment and automatic controls are installed. (69) Although it is the ultimate goal to perform maintenance with the minimum required level of manpower, the maintenance workforce should not be reduced at the expense of inefficient operation. Maintenance requires people and without the adequate number, it cannot and will not function effectively.

No generalization is possible regarding the strength of maintenance workforce. Many attempts have been made to establish bench-mark figures from averages in various branches of industry but comparisons hold true only to a limited degree. Strength of the maintenance workforce depends on factors such as: (84)

- the degree of mechanization;
- the complexity, age, amount and condition of equipment;
- the degree of training and craft skills;
- the organizational structure of the department;
- the degree of "crisis" management allowed;
- the type and level of front-line supervision;
- the motivation of craftmen.

While the importance of each of the above factors will vary from operation to operation, individually and/or in combination, they will all have some influence on manpower requirements in every maintenance situation.

Reducing maintenance manpower requirement means significant dollar-savings, especially if the upward trend in labour/material cost ratio continues; it has moved already from 1:1 in 1946 to a reported 2:1 in 1976. (81) However, reduction should not be arbitrary; it should be based on the comprehensive assessment of the scope and amount of work in the individual situation.

Today, reducing the size of the workforce of mine maintenance operations is very desirable not only because of the cost associated with maintenance labour, but even more important, because of the problems encountered in securing suitably skilled and experienced craftmen. Many of the factors that influence maintenance manpower requirements are beyond the control of individual operations, for example, the degree of mechanization which is so essential to the achievement of high productivity. However, steps can still be taken to systematically reduce the size of the maintenance workforce. The following are some recommended steps: (29, 69, 84)

(a) Reduce the reliance on "crisis" management: Studies (29) have indicated that a "crisis" environment in the maintenance workplace creates the need for 25% - 30% more manpower than the planned, organized approach. Unlike the "crisis" approach, planned maintenance facilitates the prediction of the workload and therefore manpower requirement can be balanced against this load.

(b) Adopt the organizational configuration that is best suited for the maintenance department: For example, (29) it takes up to 30% more people in an area configuration to do a given amount of work than it takes with a properly centralized maintenance organization.

(c) Employ contract maintenance if and when possible: This eliminates employment of full-time craftmen simply to handle peak loads and highly skilled jobs.

(d) Increase the potential of the workforce: Intensify training programs with particular emphasis on multi-craft training. Also, multicraft workers, who must have more skills than regular journeymen, should be taught to solve technical problems as well as to handle regular maintenance jobs.

(e) Improve the quality of front-line supervision: Well trained foremen are the key to optimizing the utilization of the maintenance workforce. The higher the utilization of available manpower, the smaller the size of the workforce required.

(f) Provide incentives, both financial and non-financial, to motivate craftmen to exert more effort during work, special emphasis should be placed on such non-financial incentives as working conditions, safety, job status and job recognition.

Although the above steps will aid in reducing maintenance manpower requirements in most situations, analytical techniques which will be discussed in chapter five, must be applied if optimization is required.

3.5 Selecting Personnel and Defining Responsibilities

3.5.1 Selecting Maintenance Personnel

The best assurance a company can have against hiring unqualified maintenance supervisors and workers is to establish a system of personnel selection, aimed at obtaining and qualifying good individuals. It need not be elaborate and expensive; in its simplest form it need only determine whether a person is qualified to perform the duties that will be expected of him.

The selection of maintenance personnel - supervisory, administrative and skilled - is paramount to the success of any maintenance organization; (62) any one of these personnel can make or break an ongoing program. Each individual's experience, attitude, technical competence and maturity directly affects the department's performance.

In striving to obtain optimum performance from all its personnel, the maintenance department should set down specific personal characteristics for each of the maintenance positions. These characteristics should include education, experience, technical ability, initiative, ability to work with others, ability to work without supervision and willingness to take on any maintenance challenge. A careful review of all personnel to determine their attributes and also their shortcomings should be conducted periodically.

Because all maintenance departments are not structured alike, and personnel duties are not the same, the required capabilities of personnel may vary from company to company. However, the above-mentioned characteristics stand out as being essential for a successful maintenance supervisor or administrator or worker. It is important that each maintenance job be filled by a person who has the highest possible rating in the list of characteristics established by the department for that position.

Good selection means lower training costs and selection must be followed by inhouse training.

3.5.2 Defining Responsibilities of Key Personnel

Having selected supervisory and administrative personnel for key positions within the department, the next step is establishing their responsibilities. Defining the responsibilities of key personnel is essential for ensuring their effective performance. (63) Such definitions should take the form of carefully prepared job descriptions, enabling personnel to act with confidence within the defined limits. Also, care should be taken to ensure that there are no gaps in the procedures and that there is no overlapping in duties between related functions; they should also undergo periodic revision.

Responsibility and authority, in a sense, are one and the same. A person should not be assigned responsibility without having the authority to follow through. Once responsibilities have been established, delegating authority is the next logical step.

Within the department, the various managerial personnel, including superintendent, supervisor, engineer, planners, inspectors and foremen, should all have their specific place in the organizational arrangement, each with the necessary degree of authority. It is also necessary to establish lines of authority between front-line supervisors for the different shifts. Usually, equal authority is delegated to each shift supervisor, thus placing them on the same level within the organization. (7, 85)

3.6 Training

Although most operations pay some attention to training, it is very often done on a periodic basis and without a well-planned program. (69) Maintenance management has the habit of ignoring training and assuming that new and inexperienced workers will become proficient in their job simply through on-the-job training efforts. In the majority of cases, craftmen learn their jobs from fellow employees who themselves, may not have received any formal training. For example, (17, 74) for a number of years at Falconbridge Nickel, Sudbury Operations, the training of maintenance workers was mostly a "learn-on-the-job" proposition. It was discovered that this uncoordinated approach to training resulted in the majority of workers receiving no formal training and, whenever some training was received, it differed widely for similar crafts. Moreover, the lack of accurate data on the training and skills of employees created problems in jobposting selections.

Not only craftmen require training, all personnel participating in the maintenance management program - planners, schedulers, inspectors, supervisors, etc. - should be trained in their respective tasks. In addition, although important prior to the introduction of a management program, training should not be restricted to this period. Training should be an ongoing exercise, continually identifying areas in need of performance and/or productivity improvement.

Large operations are most likely to have a function entirely devoted to training activities. However, in small operations, the maintenance department is usually responsible for fulfilling its own training needs.

3.6.1 Developing a Maintenance Training Program

The following are the steps, in sequence, to be taken in developing a maintenance training program: (47)

(a) Conduct a survey to establish the overall need of the department. Emphasis should be placed on identifying specific areas of weakness.

(b) Based on the results of the survey, discuss and develop the objective of the training program.

(c) Develop and use a questionnaire to inventory skills of personnel. If properly summarized, the skills inventory should reveal:

- the extent and depth of department skills
- previously unrecognized skills
- previously unknown deficiencies.

(d) Investigate what tools are available for use in training. Search should include visits to instutions of higher learning and discussions with consultants and equipment manufacturers.

(e) Design, develop and outline in-house training programs; modular programs (17, 74) have proven successful in a number of operations.

(f) Determine who needs training within the department; spend time developing individualized programs.

(g) Set up training facilities, select trainers and get the program on the way.

(h) Assess the program continuously to determine whether information is being received and understood by trainees.

3.7 Maintenance - Production Co-operation

Over a period of time, the maintenance department interacts with all other departments in the organization. However, interaction between maintenance and production is paramount. Even though maintenance is normally regarded as the primary support for production, the assistance and co-operation of production personnel is essential to attaining the optimum in maintenance performance.

Lack of co-operation from the production department can defeat the efforts of the maintenance department. Careless operating techniques can lead to major equipment downtimes that tax the capabilities of maintenance personnel. In an ongoing operation, and even more important in a relatively new one, help from production personnel is vital if maintenance is to detect and solve recurring equipment problems. The willingness of production to make equipment available when requested by maintenance is a significant factor in simplifying the scheduling of shutdowns or major overhauls (45).

Alert equipment operators can help greatly by reporting to maintenance any abnormal sounds or other signs of trouble, thereby reducing the possibility of lengthy downtime because of excessive damage to equipment.

Moreover, production and maintenance should exchange timely and useful information at all levels, (see Figure 3.2) This is only possible if the organization allows continuous interaction between the two groups of personnel. In some operations, this concept of continuous interaction is taken to the very extreme. Production and maintenance supervisory personnel are rotated giving each group an opportunity to experience and appreciate the problems of the other. (45)

The existence of this level of co-operation, coupled with timely and effective communication between the two departments, leads to an optimum production-maintenance atmosphere and a smooth operation of the maintenance management program.

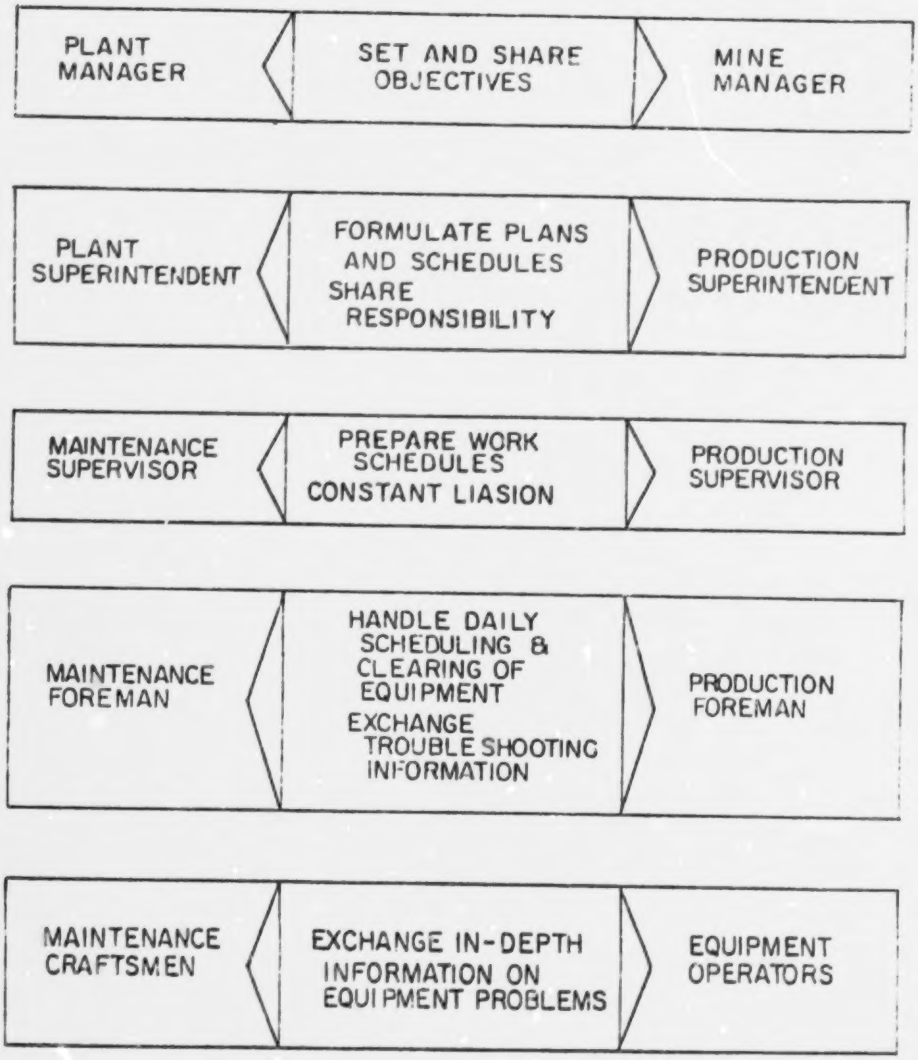

PLANT MANAGER
SET AND SHARE OBJECTIVES
MINE MANAGER
PLANT SUPERINTENDENT
FORMULATE PLANS AND SCHEDULES
SHARE RESPONSIBILITY
PRODUCTION SUPERINTENDENT
MAINTENANCE SUPERVISOR
PREPARE WORK SCHEDULES
CONSTANT LIASION
PRODUCTION SUPERVISOR
MAINTENANCE FOREMAN
HANDLE DAILY SCHEDULING & CLEARING OF EQUIPMENT
EXCHANGE TROUBLE SHOOTING INFORMATION
PRODUCTION FOREMAN
MAINTENANCE CRAFTSMEN
EXCHANGE IN-DEPTH INFORMATION ON EQUIPMENT PROBLEMS
EQUIPMENT OPERATORS

Fig. 3.2 Optimum relationships - maintenance&production (63)

3.8 Workshops and Facilities

Maintenance organization is not complete without due consideration to workshops and shop facilities. With well organized shops and facilities, prompt and effective maintenance can be accomplished.

It is difficult to be precise as to what mine shops are, since they vary widely in scope of work handled and equipment. Mine shops generally are establishments where work beyond the removal and replacement of parts is carried out. Their main business is major repairs and overhaul but may include facilities for manufacturing and reconditioning spare parts. No prescription can be given for a typical mine shop however, trends in the industry at large are discussed.

3.8.1 Shop Location

Where several mines are operated by a single company, the question arises as to whether to have a shop at each operation or a big central shop serving all. The trend seems to be towards centralizing the main shop, especially where good transportation connections are available. These main shops may include types aside from the general overhaul and repair facilities. Examples are: conveyor-belt shop, welding shop, tire shop and mine-car shop. Such shops may be separate or may be incorporated into the main shop via separate rooms or bays.

Underground-Mine Shops - A few deep mines make a practice of maintaining equipment up to the stage of semi-overhaul in the working section. However, as a general rule, main deep-mine shops are located on the surface near suitable mine openings. In some special cases, shops are provided underground for specific needs. These shops usually are located near the man-and-supply shaft and are mounted on skids for ease of moving as mining shifts from one location to another.

Surface-Mine Shops - Central location and convenient access are the main considerations involved in locating surface-mine shops. Very often, the considerations result in the shop being located with other mine facilities, such as mine office and the processing plant - especially since large units are repaired in the field and mobile units, such as trucks and tractors, can be brought in under their own power or by the use of transporters.

3.8.2 Mobile Repair Units -

Underground Mines - Skid mounted "maintenance centres" are among the newer type of mobile repair units. (7) Designed particularly for trackless mining and moved by hitching them to a shuttle car, the centre consists of 1.5 X 1.5 X 4 meters steel tanks with flat tops providing bench surfaces for work.

For bringing equipment to the surface, crawler-mounted pullers or carriers have been found very useful at a number of mines. Once on the surface, lowbed transporters speed up transportation to the main shop and save wear and tear on the units.

Surface Mines - The repairman's jeep, with space for carrying parts and tools, has become a fixture at many surface mines because of the speed with which it can deliver both men and material to the scene of a breakdown. Other mobile repair units include:

- small-tool truck
- large-tool trailer
- lowbed transporter
- small-parts truck
- truck-mounted crane
- welding truck
- fuel and lubrication trucks.

3.8.3 Shop Facilities

Even the simplest deep-mine shop should be equipped with a pit, hoisting facilities and a parts storeroom, plus the necessary special tools required for the type of work carried out. Parts-cleaning equipment should be installed to speed up inspection and to facilitate the detection of defects and subsequent repair work.

At the other end of the scale, surface shops should be equipped to handle everything up to complete desmantling and reassembly of every type of equipment in the operation. Additional facilities in these shops should include overhead cranes, hoists, compressed air and gas, welding lines and outlets, arc welders and specialized equipment such as lathes, drills, grinders and presses.

Certain permanent facilities of a shop-type serve very useful purposes in processing plants and on large equipment such as draglines and shovels. Examples are compressed air and welding gas lines and outlets. Time-saving is the major advantage.

3.8.4 Communication

A good communication system from the face or pit to the main office and shop will pay for itself through reduction in breakdown losses alone. In surface operations, two-way radios is one of the answers and include certain mobile units in the supertendent's jeep, the foreman's jeep and the cabs of key units such as stripping draglines and shovels. A reliable telephone system yields similar results in underground mines.

3.9 Conclusion

Contrary to popular belief, maintenance can be managed and controlled just as effectively as any other industrial function, however, good organization is the key element of success.

Of the five esential elements mentioned in Chapter 1, organization must be seen as the primary one since it provides the framework within which the other elements can function effectively. It also ensures adequate lines of authority and clearly defined responsibilities for all the personnel involved, allowing them to appreciate the scope of their actions. In the absence of an effective organization maintenance management becomes a complex task plagued by friction and misunderstanding.

It must be emphasized that regardless of the size of the organization, all the essential functions must be covered. In a small organization this can be best achieved, without increasing the number of personnel, by grouping certain functions together.

In essence, a good organization is the backbone of the maintenance management program, allowing maintenance to function as a single unit rather than as complex, widely spread and isolated functions.

Chapter 4

SYSTEMS AND PROCEDURES

Necessary to any maintenance management program are systems and procedures which provide information and instructions for personnel involved with the program. To be effective, these systems and procedures must cover four main administrative areas: (29)

- paperwork including equipment inventory lists, equipment data/history cards, work orders, priority lists and time cards
- stores operation and control
- standards development and application
- budgeting
- critical problem reporting and analysis.

The systems and procedures for these five areas must be designed as an integral whole because there are many interelationships. Moreover, as maintenance dynamics increase, systems get more sophisticated but not necessarily more effective. Elaborate systems and procedures usually generate unnecessary paperwork which makes control virtually impossible. It follows that systems should be as simple as is practicable, capable of dealing with frequent changes to the program without incurring major administrative and clerical problems, and they should generate a minimum of paperwork. (29)

Having the optimum in systems and procedures helps maintenance management do an effective job and minimize the occurrence of misunderstindings. (63) This chapter deals with the features of systems that tend to optimize their effectiveness.

4.1 Paperwork System

In many maintenance situations, the importance of the paperwork system is underestimated. A well designed paperwork system performs the following important functions: (84)

- initiaties action, by identifying jobs and dates
- collects data, by describing actions taken
- control operations, by describing actions taken.

Information accumulates as a form passes from one stage to another but unless a form accomplishes one or more of the above tasks it is useless and should not be a part of the system.

Maintenance forms are commonly adopted from other operations with the result that they ask for information that is not really necessary. Instead, the paperwork system should be designed for and tailored to the needs of a particular operation; clerical procedures should allow only relevant data to be recorded and should permit easy retrieval and interpretation. Descriptions of the most commonly needed forms follow.

4.1.1 Equipment Inventory List

One of the primary tasks in the preparation of a maintenance management program is the developing of an accurate list of available plant and equipment. This list which is usually referred to as an "equipment inventory list" (84) or an "equipment register" (7) should be one of the first documents prepared, since it is virtually impossible to proceed effectively without it.

As a first step, it must be decided how the different equipment will be grouped - eg. mechanical, electrical, safety etc. - then what sub-divisions will be used within each group. For example, groups can be sub-divided: (84)

- by location, departments, area, etc.
- by type, trucks, shovels, drills, etc.
- by function, mining, development, milling, etc.

Having selected one of these, plant and equipment are listed in their respective groups and identified by name and a number. A well-prepared equipment list will enable the development of a coding system.

The equipment list should always be up-to-date. As such, it should be prepared in a form that allows easy corrections, deletions and additions. One way in which this is done is to have the original on tracing paper and to make blueprints for distribution. (27) Changes can then be easily introduced.

In the coal mining operations of the U.K., the equipment list is complemented by layout diagrams of the mine and processing plant. (27) These layout diagrams identify the locations of various equipment by identifying items by the code number established by the equipment list. Distributed lists and layout diagrams should be recalled and revised as often as updating is necessary.

4.1.2 Equipment Data Card

The equipment inventory list is not made redundant by the use of equipment data cards, in fact, the two complement each other. Besides, the list serves purposes that the card cannot.

The data card should show the equipment number and the basic name plate information as a heading. The details of the card should include: (84)

1. Technical Data and Description
    - speeds, capacity, rating
    - cost and purchase date
    - weight and dimensions
    - manufacturer and model number

2. Financial Data
    - cost
    - account number
    - cost centre number

3. Service Schedules
    - lubrication sheet number
    - inspection sheet number
    - spare parts list number
    - overhaul sheet number
    - substitute parts list number

The form that cards take is a matter of preference, however, visible-edge cards (7) which are filed in book units have proven successful in the U.K.

4.1.3 Equipment History Card

This can be a separate card but, to reduce the quantity of paper in the system, the reverse side of the equipment data card may be used. The equipment history card should contain a complete record of all work done on, and by the equipment. Information on the card should include: (7)

- nature and time of repairs
- work order number
- downtime
- labour hours
- costs - material, total, and accumulated
- units of production or tonnage handled

Sometimes, a parts-used card accompanies the historical-data card (7). Parts used are detailed by catalog number and description; small hardware such as nuts and bolts etc. are not necessarily recorded. Any delay time for parts or material delivery is also recorded.

Equipment data cards form the basis of the historical-data record system which provide useful indicators to reflect the status of the program.

4.1.4 Work Order

The request for maintenance work, the work order, is undoubtedly the key document in the maintenance management program. (57) Every program, manual or computerized, must have some form of this work-requesting document. It constitutes the link between the equipment in need of service and the organization as a whole and, in particular, the department involved in providing the service. By documenting all work requests there is an accountability so that each work order can be tracked through its completion.

The work-order form serves several purposes including: (31)

1. Identification of the equipment involved, the problem, and the immediate impact of the problem on safety and production.

2. The planner's listing of tasks to be performed and their sequence; crafts and estimated manhours required, list of materials required; drawings; personnel support required; and cost account.

3. Documentation of action taken, crafts and manhours used, materials and equipment used, date and time when repairs were done, and cause of the problem.

Essentially, a work order should tell craftmen what work is to be done and should include information on the manhours, materials and equipment required to do the job. Its originator should ensure that instructions are clear and, if necessary, a sketch or working drawing should be provided. Once issued, it must follow a predetermined route so that essential control data is generated along the way. (see Figure 4.1).

Requests for maintenance work may be initiated by any personnel within the organization, however, it must be approved by someone with the delegated authority, preferably, the person who is financially responsible for the operation and maintenance of the equipment involved. A good system to adopt is the establishment of a list of personnel who are the only ones authorized to approve maintenance work requests. (15, 19)

All requests for maintenance work should be made through the established work-order system. However, different requesting procedures may be used for major, repetitive emergency jobs. The following are the usual procedures: (55, 57, 69, 84)

- Major jobs: separate written work order for each job

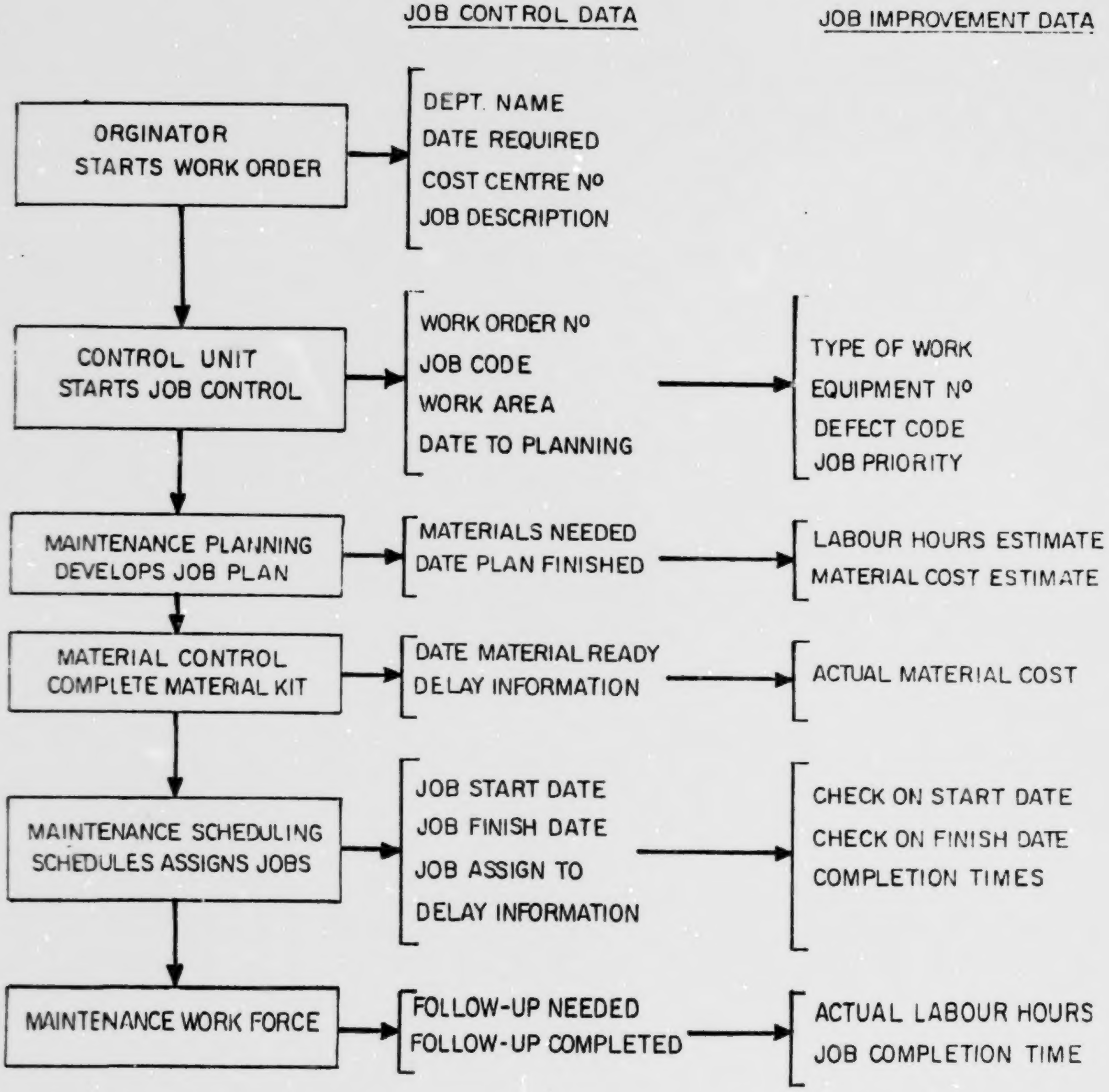

JOB CONTROL DATA
JOB IMPROVEMENT DATA
ORGINATOR STARTS WORK ORDER
DEPT. NAME
DATE REQUIRED
COST CENTRE Nº
JOB DESCRIPTION
CONTROL UNIT STARTS JOB CONTROL
WORK ORDER Nº
JOB CODE
WORK AREA
DATE TO PLANNING
TYPE OF WORK
EQUIPMENT Nº
DEFECT CODE
JOB PRIORITY
MAINTENANCE PLANNING DEVELOPS JOB PLAN
MATERIALS NEEDED
DATE PLAN FINISHED
LABOUR HOURS ESTIMATE
MATERIAL COST ESTIMATE
MATERIAL CONTROL COMPLETE MATERIAL KIT
DATE MATERIAL READY
DELAY INFORMATION
ACTUAL MATERIAL COST
MAINTENANCE SCHEDULING SCHEDULES ASSIGNS JOBS
JOB START DATE
JOB FINISH DATE
JOB ASSIGN TO
DELAY INFORMATION
CHECK ON START DATE
CHECK ON FINISH DATE
COMPLETION TIMES
MAINTENANCE WORK FORCE
FOLLOW-UP NEEDED
FOLLOW-UP COMPLETED
ACTUAL LABOUR HOURS
JOB COMPLETION TIME

Fig. 4.1 Basic work order flow and data generation (62)

- Repetitive jobs: Pre-printed job cards or checklists for each group of equipment, listing the jobs to be done and their frequency, with check marking to indicate completion and a remarks column to pass on information

- Emergency jobs: initiated by directly calling the appropriate foreman or supervisor and having the work order forwarded while the job is in progress

There is no unanimity as to the appropriate number of copies of the work order, however, four copies distributed as shown below seem to be common to many operations: (7, 52, 69)

- Originator
- Maintenance Foreman/Superintendent
- Control Unit
- Accounting

Completed work orders should become a part of the historical-data record system.

The work order system must be the only channel for requesting and authorizing maintenance work.. It must be designed to effect control over all maintenance activities but must also be flexible enough to deal with frequent changes to the program. Information that might be included on a work-order form is shown in Table 4.1.

The format of the work order varies from company to company and may not include all the information shown in Table 4.1. Manual maintenance management programs usually use a less elaborate work-order form than their computerized counterparts mainly because of the problems encountered with handling the data generated. Because of the increased capability of a computerized maintenance program, the work-order form is usually re-designed prior to the implementation of such a program. Two major modifications are usually made: (57, 69)

Table 4.1 Information on a Work-Order Form (84)

Identification	Action Required	Action Taken	Computation
Department or area	Actual problem	Work done	Total cost of labour
Date requested	Reason for defect	Work identification	Cost of stores issue
Date needed	Work instruction	Actual man-hours	Cost of purchases
Equipment code	Class of job	Dates worked	Total cost
Equipment type and name	Craft required	Requisition number	Total man-hours
Work order number	Material required	Completion date	
Priority number	Estimated man-hours	Approving signature	
Account number	Authorizing signature		

- information is more detailed and in quantitative terms
- a series of code numbers are used for equipment and activity classification

Basically, the work order should always be compatible with the program for which it is designed. For either a manual or a computerized program, the work order must provide for the collection and generation of adequate data to effectively control the maintenance operations.

4.1.5 Priority Procedure

Necessary to any maintenance program is a procedure for assigning priorities to jobs. It must be tied closely to the work-order system.

Although the originator of a job request is required to specify a desired completion date, in the absence of a job priority procedure almost every job becomes an emergency, requiring immediate attention. In many cases, these make-believe emergencies consume as much as 80 percent of the available man-hours. (22) Because emergency work is usually inefficient and expensive, minimizing emergencies is paramount.

Man-hours for emergency work can best be reduced by defining priority categories. The following is a suggested list of definitions: (22, 69)

- Emergency Priority:	work that, if not undertaken immediately will cause a safety hazard, major production loss or major damage to property and/or equipment. Action should be immediate.
- High Priority:	work required to ensure uninterrupted operation. Action should be within a maximum period of three days.

- Low Priority: work required to prevent long-range plant/equipment deterioration. Action should be within 14 days.
- Shutdown Priority: work that requires major equipment to be out of service. Action should comply with scheduled shutdown period.

4.1.6 Time-reporting Procedure

Accurate accounting of time is essential for maintenance cost control and accountability. The reporting procedure adopted must be compatible with the work order system.

The basic ingredients of a good time-reporting procedure include the following: (22, 69)

- Individual daily time cards, containing employee's identification number, brief description of work done, work order number, and time spent on job
- Review of completed daily time cards by supervisor
- Daily/weekly processing of completed time cards
- Periodic comparison of time cards and completed work orders.

The reporting procedure should allow for the recording of time on both the time cards and the work orders. This serves as a good cross-checking device.

4.1.7 Service Instructions

These relate to regular, repetitive maintenance activities that are performed throughout the life of the equipment. These include: (52, 84)

- lubrication instructions
- inspection routines
- periodic adjustments
- preventive replacement of components
- instructions for overhaul
- spare parts lists.

In a number of applications service instructions take the form of checklists. Their implementation does not require highly skilled personnel, and markings by code numbers on the equipment should facilitate correct perfromance. Most commonly used checklists, such as those for lubrication and/or inspection, are provided by the manufacturer with a check-off column and space for descriptive assessment.

In compiling checklists, the equipment manual should be consulted and past history of similar units should be taken into consideration. Each checklist should identify the equipment, frequency of service in terms of operating hours or tonnage of output, trade groups required and the estimated time for the job. The provision of a diagram facilitates the work.

Checklist-type service instructions have been used for a number of years, with good success, in many of the coal mining operations of the United Kingdom (52).

4.1.8 Work Specifications

Work specifications define the methods and means of performing certain jobs, thereby ensuring that they are carried out in a uniform manner. They serve as a guide for craftmen, enabling them to comply with prescribed practices.

Precise specifications for different maintenance activities vary in depth and presentation according to the system and the complexity of the item to be maintained. In manual maintenance programs, specifications are usually presented as a part of the work order. In the simplest case, reference is made to specfications (usually manufacturers' manual) on the work card issued to the maintenance staff. This practice is mainly to reduce the amount of paper in a system.

The introduction of work-control systems, which is essential to highly mechanized operations such as mining, requires a certain degree of timing, and detailed work specifications are essential for this purpose. In such cases, specifications may be separate documents and can be issued as cards or manuals. If produced as cards, they are protected from wear, issued from the control office and returned after use for reissue.

Much maintenance work can be specified in detail - preventive, overhaul or corrective. Specifications for all maintenance work must be subject to modification in content and fequency as experience is gained.

4.2 Maintenance Stores

Maintenance materials are an important part of maintenance costs and their significance is often overlooked because they are considered a small portion of the total cost. However, an analysis of total maintenance costs shows that maintenance materials are usually about 40 percent of total maintenance costs and also that they are a controllable cost, second only to maintenance labour. (78)

The lack of necessary spares and materials can have a detrimental effect on maintenance performance. Methods of parts identification, location identification, parts storage and availability assurance, the protection given to items in storage, and the procedures for material issue and delivery must all be given serious consideration.

Maintenance stores performance should be measured by one basic criterion: Does it adequately support the maintenance operation at minimum cost?

What to store? From the standpoint of mine maintenance, the most important classification of stores is spare parts. These should be categorized ranging from "critical" to "normal" stock. Critical spares are those whose unavailability would cause all or a portion of production to stop or slow down. Normal spares would include those items that are frequently used. Tools, equipment and other maintenance materials should also be considered in stores stock. A simple rule to follow is that all maintenance items should be included in the stores inventory. (85)

The focal point for the control of maintenance materials is maintenance stores and it may be organized under several systems. In mine maintenance, stores is considered a major service and probably should be set up as a separate facility. However, the decision as to whether maintenance stores should be centralized or decentralized must be made by the particular operation; no generalization can be made as to which system serves any given operation best. Nevertheless, the trend in the industry at large seems to be one main stores supported by several strategically located satellite stores (55, 15).

4.2.1 Stores Service

Adequate storage space, good layout, and a locative system improve stores service. Adequate stores manning also minimizes delays in servicing maintenance personnel.

Stores procedures and practices should allow quick and efficient service. The objective should be to minimize the time required for issuing items without neglecting the recording aspects. Some of the measures that are adopted include: (78, 84, 104)

- free issuing, whereby small items such as nuts, bolts, screws and washers are provided in a series of open bins which are available to all maintenance staff at all times.

- satellite stores on mobile racks carrying a selection of frequently used items.

- marking and identification of shelves and bins inside the stores and a systematic division of items to facilitate locating.

- pre-tagging of costly items showing identification and equipment for which they are intended.

- pre-printing issue slips for standard and frequently used items.

- pre-selecting and pre-packaging sets of tools and parts for certain repetitive jobs.

- grouping the items and components that are similar for different equipment.

- coding items and components and providing stores manual with cross-reference to stores bin number.

The adoption of these measures satisfy both the requirements of expediency in issuing and the recording of essential control information.

4.2.2 Stores Control

Stores control relates mainly to:

- maintaining of adequate stock levels
- accounting for the issue of items to jobs.

The following are some of the basic elements of a manually controlled system: (78, 84)

- Bin Cards, for recording issues as they take place and to facilitate the taking of inventory.

- Stock Cards, for recording balance in stock and orders placed, and maximum/minimum levels.

- Requisition Slips, for listing required items, quantities, job number, charge account number, and person receiving items.

- Purchase Requests, for indicating date and quantities ordered to replenish stocks.

- Delivery Notes, arrive at stores with items ordered, allow for accounting with suppliers.

- Invoices, issued by suppliers, indicating cost per item.

- Cost Centres, account codes to which stores issues are charged.

With a manually controlled stores system stock levels can only be ensured by visual checks of shelves or bins, bin cards and/or stock cards. These checks are usually time consuming, laborious and very often inaccurate, but for small stores operation, the manual system is tolerable. However, on a larger scale the inefficiencies become too costly and management must consider some form of electronic data processing. (see Chapter 7)

Maintenance materials can often be managed more effectively with a corresponding reduction in the total cost of maintenance. The reader can evaluate his maintenance materials controls by comparing present practices to those listing in the "Maintenance Material Check List" shown in Table 4.2.

4.2.3 Stock Control

This is probably the most frequently dealt with aspect of maintenance stores. Essentially, stock control involves two parameters:

- the Economic Order Quantity (EOQ)
- the Re-order point.

In a maintenance environment, both parameters are affected by such factors as: (69)

- maintenance scheduling demands
- production downtime considerations
- stores system, centralized or decentralized
- lead times
- suppliers location.

How much to order? Perhaps the most important consideration in determining the economic order quantity is the average number of units used during a given time. This is usually determined by analysis of material withdrawals, using the stores requisition cards. Other considerations include storage and the cost of carrying inventory in stock. Excess inventory of maintenance can occur for the same reasons as stockouts: inadequate usage history, unrealistic lead times, and inproper re-order points. In new operations without usage history, manufacturers' recommendations are usually

Table 4.2 Maintenance Materials Checklist (78)

Status	Problem or Question	Action or Control
Stockouts	Usage history Lead times Reorder points	Maintain and audit record Audit regularly Audit, change as necessary
Stock Identification	Difficult to find Duplicate part numbers	-Cross index Standardize and cross index
Lost or Misplaced Stock	Lack of identification	-Mark by hand Keep in marked bin Scrap if not identified
Scrap or Waste Stock	Excess material drawn Excess not returned Cannibalize	Identify, return to stock Minimize excess withdrawn Scrap -Use when no other way
Obsolete Material	Value reduced (becomes scrap)	-Avoid overstocking -Plan for obsolescence -Sell part with equipment -Audit and scrap
Outside Storage	Weather damage Lost in snow or mud	-Cover, spray, protect -Inspect and clean regularly -Keep inventory and location
Overstock	Excess inventory	-Better usage records, lead-times and reorder points -Rationalize manufacturers' recommendations
Economic Order Quantities	Minimize purchase and carrying costs	-Purchasing department should develop economic order quantities
Quality of Material	Under or over quality Purchase of substitute	-Lack of adequate specifications -Notify user for approval
Communications	Delayed delivery	-Notify user to adjust plans
Insurance Items	Identified and controlled Immediately available	-Carry in stock -Inter or intracompany stores
Special Nonstock Items	Bill of material Adequate lead time Assure availability	-Engineering department should provide -Plan ahead of need -Assemble onsite
Inspection and Parts Lists	Repair parts not known until equipment torn down	-Inspect to determine needs -Order parts lists
Used Material Reporting	Quantities used Location of repair	-Report on work order -Note on sketch
Outside Contracting	Equipment, skills, and manpower not available	-Some contracting expected -Use to reduce temporary backlogs
Lubrication Materials	Lack of standardization Need for specifications Need for training to use	-Oil company surveys -Keep lubrication records -Recognize job importance
Free Stock	Need reorder points Pilferage	-Barrier stock -Bins near or in stores counter
Indirect Maintenance Material	Stock control	-Indirect material account -Barrier stock
Maintenance Tools	Distribution of costs Return to stores	-Indirect material account -Issue by tool check

used. (78) However, because such recommendations can lead to excessive inventory, usage history should be accumulated to improve on same.

When to order? The "re-order point" is the point (number of units) at which the stock of any unit is so reduced that the supplier should be notified to initiate delivery of a fixed quantity of that unit. Re-order points must be continually reviewed and adjusted in view of the experience gained regarding lead times and suppliers response.

A number of analytical techniques, both simplified and sophisticated, can be employed to aid decision making in both of the above areas. (see Chapter 8). Computer applications are also well developed and are used by a number of large operations (see Chapter 7).

For effective stock control, a simple rule is recommended: (85) "Do not allow direct ordering of maintenance materials; use your inventory control and requisition systems to draw all materials from stock".

4.2.4 Material Supply

A recent trend in maintenance materials control, evident at a few U.K. coal mines (7) and at Quebec Iron and Titanium Corporation (15), is the setting up of a material control center. The center is fully responsible for the delivery of all materials to the job site. It is headed by a supervisor or director of materials and manned by a group of materials controllers or expediters.

Materials controllers are assigned to area planners in the field but report to the supervisor of materials. They work from the planner's office and are responsible for materials job costing, stores material reservations, and for arrangements with stores for on-time materials delivery to the job site. They also requisition materials through purchasing, expedite materials from suppliers, and replenish fast-moving spares in satellite stores.

The concept has proven very successful and has virtually eliminated delays due to lack of spares or waiting on stores.

4.2.5 Interface With Purchasing

Since the responsibility for replenishing stores stock normally rests with the purchasing department, a strong liason should be established between purchasing and maintenance stores personnel. Some operations have a priority system by which maintenance indicates the degree to which purchase orders should be expedited. In other situations, a purchasing agent is actually assigned to the maintenance stores or maintenance personnel to the purchasing department.

In some operations where purchasing is not a separate department, maintenance is authorized to deal with suppliers and to charge materials to open purchase orders. Examples (66) are the off-shore oil operations in the U.K.

4.3 Maintenance Standards

Standards, as applied in maintenance, are primarily for estimation and measurement purposes. The simplest standard, and the cheapest to apply, is an estimate of how long a job should take. However, a maintenance standard is really made up of three parts: (69)

- the sequence of events required to perform a job
- a listing of crafts, and the manhours required for each craft
- a listing of the materials, tools and equipment required.

The introduction of a "standard program" is crucial to the success of the maintenance management program. In fact, planning, scheduling, and performance measurement would be virtually impossible without such a program. In order to make the most effective use of the developed standards, it is necessary to be able to quantify maintenance effectiveness; some productivity index must be established prior to using a standards program.

A Standards program is usually introduced into the operation by an internal group, such as industrial engineers (in large operations) or experienced foremen (small operations); or it may be introduced by an outside consultant who comes into the maintenance department to design and set up the program (69). Regardless of the method of introduction, it is essential that all personnel who are to work with the standards be involved from the beginning with those who set up the program. Operations that start with a standards program appear to have a much greater degree of success with it than do operations that introduce such a program some time after operations have started. The primary reason for the failure of the latter seems to be failure to win acceptance of the program by the personnel who must work with it. The best method of avoiding this problem is to conduct a series of orientation meetings with maintenance planners,schedulers, supervisors and craftmen to ensúre both understanding and acceptance of the program before its use begins.

4.3.1 Developing Maintenance Standards

The initial step in establishing any kind of maintenance standard is to study the kind and frequency of work. Such a study indicates that maintenance work is either repetitive or non-repetitive.

For repetitive jobs, the problem of setting standards is straightforward. Once the method has been standardized and the operation has been measured, the same standard can be applied repeatedly. The following steps are followed when developing a meaningful standard for a repetitive job: (54, 55)

- The job is identified and assigned a code
- The job is described in detail
- Material and spare parts are identified and specified
- Best method is identified and specified
- Tools, special material, handling equipment and safety instructions are stated
- Crew size is specified
- Job duration is measured, and a time range specified.

Maintenance supervisors and planners should collect this information for a number of repetitive jobs. Because of the similarity of many repetitive jobs, similar ones are often grouped together and a common standard is assigned. (54, 71, 84)

Developing standards for non-repetitive jobs is much more difficult and the key to controlling maintenance costs falls in this area. If job standards were to be developed by individual time study, the time and cost requirements would be very high and because of this high development cost, attempts have been made to develop standards based on experience, historical data and even statistical analysis of data. However, these standards are usually inaccurate, inconsistent, and sometimes unsupported by acceptable facts. (71) Moreover, all these concepts are attempts to develop exact time standards for maintenance work and expecting every worker to perfrom a job in exactly the same time is unrealistic.

A method that provides for a more realistic development of maintenance standards is "predetermined" time standards. (30, 71) These were developed specifically to solve the work-measurement problems of non-repetitive maintenance operations.

Predetermined time standards represent the average times necessary for a qualified craftman, working at a normal pace and under capable supervision and experiencing normal delays, to perform a defined amount of work, of a specified quality, while following acceptable trade methods. (71) Time studies for many maintenance operations have been conducted, and the information from such studies has been used to establish predetermined maintenance standards. Publications are available from the U.S. Government Printing Office, Washington D.C. 20401. (71)

There are a number of predetermined time standards but the two that seem to be most common in the mining industry are: (15, 19, 30)

- Universal Maintenance Standards (UMS)
- Engineered Performance Standards (EPS)

Approximately 65% of the maintenance operation at Quebec Iron and Titanium Corporation (15) is covered by the former and a similar percentage of the maintenance operation at Algoma Steel (19) is covered by the latter. UMS is also extensively used by the coal mining operations in the U.K. and the Creole Petroleum Corporation (30) of Venezuela.

4.3.2 Applying Predetermined Standards

In applying predetermined standards to maintenance work, a technique known as range-of-time or slotting (30, 71) is used. The technique recognizes that it is impractical and unrealistic to set an exact time for every maintenance job. Each job is different even though request and results may be identical. For example, the time required for changing a motor varies, depending on the condition of the holding-down bolts; if bolts are badly rusted or nuts are damaged, more time is required than if conditions are normal and bolts can be easily removed.

In the range-of-time concept, a given time is scheduled to complete a job, and this time will be the median of the range. A job that is assigned 2.0 hours for completion is expected to take 1.5 - 2.5 hours. Both the range and median established for various jobs are based on actual measurements.

Application of the slotting technique requires the use of so-called "benchmark" jobs. Benchmark jobs are those that have been carefully selected as typical of the maintenance work in the operation. They are assigned measured time values, usually from predetermined time techniques, and are classified by type and craft involved. Sometimes, benchmark time values are adopted from studies conducted in other operations, but, in every case they must be validated for similarity in methods, tools, etc.

When work orders are received, the analyst compares the work content to the closest in his collection of benchmark standards. The benchmark standard time is what determines which slot the job will fall into, and that slot is assigned as the time allowed to perform the job. When a job is required or being planned and a benchmark can be identified as identical, an exact time standard can be set. However, when an identical benchmark is not available, a work-content comparison between the benchmark job and the required job will permit an easy determination of an approximate time.

Because benchmark times do not allow for such activities as clean-up, travel etc., an allowance factor must be added to the benchmark or standard time to determine the allowable time for the job. Preparation of such standards must be in the hands of a trained analyst. He must be a maintenance man and have a thorough knowledge of the maintenance work involved in the operation.

For a standards program to be successful, it is necessary to audit, periodically, some planned work orders after the work is completed, to compare actual hours spent with the planned hours. If done on a consistent basis, these audits can reveal obsolete or inaccurate standards.

4.4 Budgeting

An essential aspect of maintenance management is the process of budgeting. A maintenance budget, like any other budget, is a financial plan which represents a projection of expenditures for some future time period. Budgeting for the maintenance department embraces the provision of financial information on labour hours, labour costs and materials expenditure, and its allocation to the various cost centres. It should be realistic in that it reflects what is expected to happen rather than what management would like to happen.

The maintenance cost budget is usually divided into cost centers. A cost center can be a geographic portion of the operation, usually a specific activity - eg. drilling and blasting, or milling. Alternatively, a cost centre can be a specific category of expenditure, eg. overhead cost. A typical breakdown and approximate allocations (although

Table 4.3 Typical Breakdown and Allocations of the Maintenance Budget (78, 109)

Expenditure Category	Share Percent (Allocation)
Labour (including overtime, sub-contracting and fringes)	40
Materials (including spares and other materials)	40
Overhead (including supervision, staff, tools and equipment, other facilities)	15
Improvements (including equipment and installations chargeable to maintenance)	5

actual budgets vary enormously) of a maintenance budget is shown in Table 4.3.

For each of the cost centres in the above categories, annual labour hours, labour costs and material costs are budgeted. Based on a preliminary work schedule, the different costs are distributed proportionately over the twelve month period. Thus, monthly cost objectives are established.

High-cost centres should be budgeted in detail with the aid of such historical data as: (7, 15)

- Cost (labour and material)
- Labour performance and utilization
- Emergency overtime
- Equipment repairs
- Frequency and extent of production downtime.

Even low-cost items should be budgeted through the use of historical data. Historical data for at least the past three years should be available for each cost centre.

Although important as a control device, the usefulness of a maintenance budget depends on the method of preparation. Clear procedures should be established, defining the methods for drawing up the budget and collecting the needed data; slack, easy-to-achieve budgets defeat the purpose of budgeting. Moreover, the practice of adding a fixed percentage to the previous year's budget should not be encouraged. Budgeting should be:

- The considered opinion of the predicted cost of maintenance, designed to meet the forecasted workload to agreed performance standards;

- A continuous exercise, i.e. data is gathered continuously and not hurriedly assembled just before budget applications are due;

- Benchmarks set at tight but realistic levels, which can be attained by efficient performance;

- Based on objectives and strategies of the department.

The fact that maintenance personnel will have to work with such a device, forces them to plan and control spending much more than they would normally do.

4.5 Critical Problem Procedure

Critical maintenance problems may fall into two categories: (40)

- Maintenance failures that cause serious/lengthy production stoppages

- Maintenance failures that cause accidents or create potentially serious safety hazards.

The maintenance management program should include a specific procedure to be followed in handling such problems. Furthermore, an immediate investigation, analysis and corrective action should be considered mandatory by top management.

Details of specific procedures will vary from operation to operation. However, the following elements are considered essential in any established procedure: (40)

1. A complete list of all events considered as critical to the operation, to be updated as experience is gained; any other event should be designated critical only by a high-level maintenance personnel, eg. engineer or superintendent.

2. Clear description of the action required by maintenance personnel in the event of any of these occurrences; details should include:

    - reporting procedure; verbal (immediate) followed by written;

  - remedial action (immediate if possible); how to initiate action, including "call-out" procedure;

  - shutdown procedure (if necessary); safety of personnel must have top priority.

3. Investigation and analysis of event; submitted report should provide answers to the following:

   - What happened? - date, time, personnel involved
   - What was impact on production?
   - What was the cause?
   - What corrective action was taken?
   - What will be done to prevent recurrence?

4. Recording procedure; a log book of all critical problems that the operation has experienced should be maintained; reports can be filed under "resolved" and "unresolved"; status of unresolved problems should be continually reviewed.

Formalizing such a procedure helps to ensure that all personnel know what is expected of them in the event of a critical problem, and also that the problem is thoroughly analyzed. Very often, critical problems re-occur because no analysis was carried out or because analysis was incomplete and offered no solution.

4.6 Conclusion

Smooth operation of the maintenance management program depends on the clear expression of how each aspect of the program is required to function. Its operating efficiency depends on incorporating suitable system features and ensuring that they are employed to the fullest extent.

The employed systems should clearly express what is required from the program, allowing everyone connected with the program to understand what is required of it. Moreover, systems should provide guidance for the actions required of maintenance personnel, guidance in what to do, and how to do it in all situations.

It is clear that effective systems must have the full and obvious support of all levels of management.

Chapter 5

MAINTENANCE STRATEGY, PLANNING AND SCHEDULING

This chapter discusses two of the closely related elements of the maintenance management program. The first section deals with the maintenance strategy or plan, describes the different maintenance actions available and how these can be put together to produce the most suitable system for the particular need. The second section deals with planning and scheduling and describes the available techniques and measures that can be employed to develop and establish effective planning and scheduling procedures.

The two elements are combined because, together, they represent the mechanics of the maintenance management program. All the day-to-day activities of the maintenance function are closely related to and take place around these elements.

5.1 The Maintenance Plan (Strategy)

It was pointed out in chapter 2 that the the objectives of maintenance must be firmly established before effort is committed to achieving them. Only when these objectives have been determined, is the operation properly equipped to consider the best way of fulfilling them and the best way of planning the course.

In any maintenance management program there must be an adequate description of the work to be carried out on each piece of equipment. The description must be sufficiently comprehensive to ensure that, not only is the work properly done and all equipment covered but also that all relevant safety actions are taken before, during, and after the maintenance task. The maintenance plan or strategy is concerned with specifying the maintenance actions required for each unit of the operation and deciding how and when such actions are to be carried out.

5.1.1 Classification and Identification of Equipment

This first step in developing a maintenance plan is important but usually tedious and difficult because it involves considerable detail, and in larger plants can also be complex. (58) For these reasons a detailed systematic approach to the task is essential.

A system (58) widely used in the industry, with a good degree of success, is one which regards large, complex equipment as a hierarchy of parts, ranked by their function and replaceability. A simplified hierarchy is shown in Figure 5.1. A mining operation is usually designed to perform its function for some forecasted production life. It can be divided into its units which perform a specific major function, eg. dump trucks or shovels. Some of the components that make up each unit will have been designed, for economic and other reasons, with a life-span less than that of the unit itself. Other components might well have a high probability of failure within their useful life. In most cases such components will have been identified at the design stage and made replaceable. It is this idea of "replaceability" that is used to classify the various items of any given piece of equipment.

The following is the usual classification of items: (57, 58)

- Permanent
  These are items (usually structural) whose useful life either determines the life of the unit or outlasts it. Replacement is generally uneconomic.
- Complex Replaceable
  These items are made up, from many components, into a complete replaceable module. Their useful life is long, but less than the life of the unit, and usually difficult to determine because of the random failure exhibited.
- Simple Replaceable
  These items are made up from one component (or very few) where one component determines the life of the item. The useful life of such items is short and relatively easy to determine.

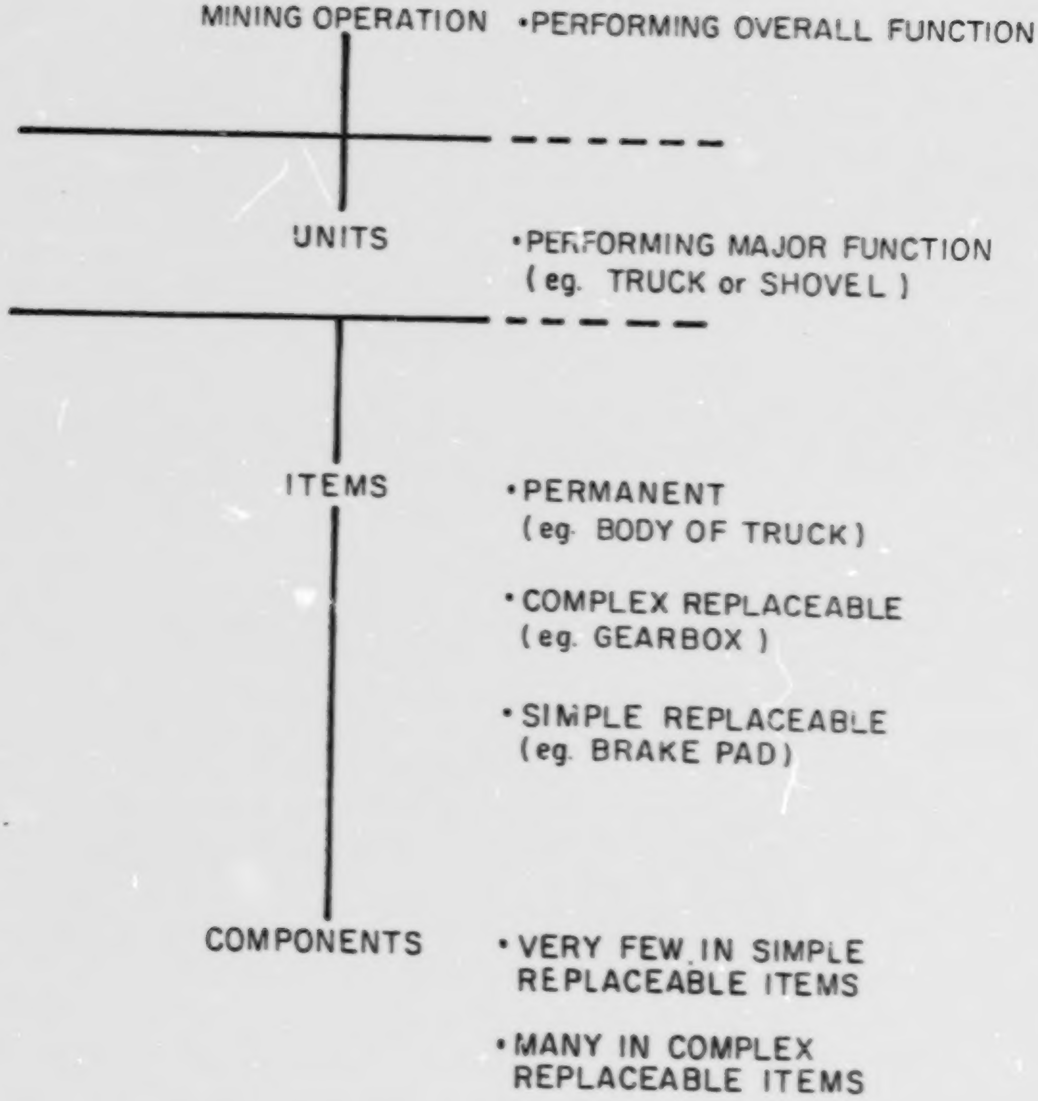

MINING OPERATION
•PERFORMING OVERALL FUNCTION
UNITS
•PERFORMING MAJOR FUNCTION (eg. TRUCK or SHOVEL)
ITEMS
•PERMANENT (eg. BODY OF TRUCK)
•COMPLEX REPLACEABLE (eg. GEARBOX)
•SIMPLE REPLACEABLE (eg. BRAKE PAD)
COMPONENTS
•VERY FEW IN SIMPLE REPLACEABLE ITEMS
•MANY IN COMPLEX REPLACEABLE ITEMS

Fig. 5.1 Equipment hierarchy (57, 59)

Some system for identification of units, items and components should next be developed. The simplest of the various systems is probably some form of numerical and/or letter coding. (39) The system may use six digit numbers (for example, 0021-21) of which the first four digits indicate the unit type; the fifth and sixth digits identify the items - motor or pump. Letters following items digits may be used to identify components (39). Such a coding system must be used throughout the program.

If a piece of equipment is to continue to function at a given desired level of availability its constituent items and components will need to be replaced and/or repaired at some point. This can be considered as the EXPECTED MAINTENANCE LOAD. In addition there will be repairs/replacements due to unexpected failures. The combination of these two loads constitutes total workload of the maintenance department, and the primary reason for formulating a maintenance plan.

Before examining the procedure for formulating the maintenance plan, it is first necessary to examine the alternative ways in which a unit can be maintained.

5.1.2 Maintenance Actions

In order to maintain a unit there are a number of courses of action that can be employed. In the simplest case the alternatives might be: (58)

- maintenance by item replacement
- maintenance by item repair.

Many factors influence the choice of such alternatives, the most important being: (58)

- stock-holding cost
- unavailability cost
- failure characteristics of the item
- nature of the maintenance task.

Having decided on the nature of the action, it is also necessary to decide on its timing. Should the maintenance action be carried out preventively, before failure? should it be based on the condition of the item? or should the item be allowed to fail? In general, maintenance actions are either preventive or corrective. (58)

Preventive Maintenance

This is maintenance carried out at pre-determined, usually fixed intervals, with the sole aim of preventing failure. (57) It includes item replacement and repair, and fixed or continuous inspection. In most cases the actions, frequencies and resources for such work can be pre-planned and scheduled to produce a predictable workload. It is this organization and preparation of maintenance work that permits employment of a stable labour force and that minimizes the number of emergency breakdowns in an operation.

Preventive maintenance can be divided into four sub-headings: (82)

a)	Running:	This involves the use of the faculties, ie. sight, smell, touch and hearing, all of which are used to check if a piece of equipment is running satisfactorily.
b)	Shutdown:	This involves the use of tools, the removal of covers, etc., to check for impending faults and make any repairs or adjustment deemed necessary. It must be planned to fit in with stoppages.
c)	Overhaul:	This involves taking the equipment out of service and is usually carried out in established workshops. It must be planned to coincide with a production stoppage, if not, replacement equipment must be made available.
d)	Lubrication:	This is a continuous activity and probably represents the most important preventive measure of all: if a piece of equipment is not sufficiently lubricated, it will inevitably wear out, resulting in breakdown and possible serious damage.

These four types of preventive maintenance can be applied, in varying degrees, to every component of any equipment. However, because they usually introduce high-costs, they are usually reserved for critical (from production and safety standpoint) and expensive items.

Preventive maintenance is only effective where the failure pattern of the item is clearly time-dependent, the item being expected to wear out within the life-span of the equipment, and where the total cost of such work is less than those of failure replacement/repair. (48, 58) However, regardless of how complete and sophisticated the program, preventive maintenance cannot completely avoid unexpected failures or emergencies and hence, the need for corrective maintenance is always present.

Corrective Maintenance

This is maintenance carried out to restore an item which has failed or where condition has become unacceptable. Often, an emergency is involved and the cost is higher than the cost of preventive action; especially, it may involve a high loss of production.

Corrective maintenance arises not only when an item fails but also when indicated by a condition-monitoring process. The basic objective is to establish the most economical method of restoring the failed or deteriorated item to an acceptable state. Clearly, the best procedure cannot be determined until after some experience has been gained - until events requiring corrective action have occurred. (58) It is only then that the influencing factors (ie. cause of failure, cost of repair/replacement, resources and unavailability) can be assessed and the type of repair determined.

Accepting that corrective maintenance does occur, it is essential to plan for it. This involves: (58)

- deciding on the type of corrective action in the event of failure
- establishing as a part of the maintenance plan,

CORRECTIVE MAINTENANCE GUIDELINES to assist in determining, at short notice, the maintenance procedure to be adopted.

Corrective maintenance is usually reserved for complex replaceable items and even then, it should be restriced to critical items of equipment since it can be very expensive. (58) A critical item in this context is one which might fail with little warning, and where the downtime costs are very high. A condition-based maintenance policy alleviates this situation since it provides time for decision-making, planning, and scheduling the maintenance action required.

Condition-based Maintenance

This is preventive maintenance initiated as a result of knowledge of the condition of an item or component from checking. (3) It is planned and carried out only when necessary and it avoids most emergencies.

Condition-based maintenance is an attractive concept in that it allows proper timing for the performance of maintenance by monitcring condition and/or performance, provided, that a monitorable parameter of deterioration can be found. (57) The guess-work or estimation in failure prediction is therefore reduced, the item life is extended and the effect of failure is minimized. One of the major advantages of this approach is that it permits corrective maintenance to be scheduled with little or no loss in production.

Totally preventing failures will generally be expensive. Moreover, regardless of how complete a preventive program, failure, with loss of production, will always occur. The duty of maintenance is to cope with these exceptions and to keep them at the lowest possible level. Condition-based maintenance can help in solving this problem by constant (sometimes continuous) monitoring of such parameters as temperature, noise, vibration, etc. When failure is approaching, the measurement of one or more of these parameters will warn the maintenance department and corrective action can be taken before failure occurs.

Condition-based maintenance is thus a powerful tool in the hand of a maintenance manager enabling him to be in full control of the condition of equipment at all times so that he can: (3)

- plan shutdowns when material and men are available
- plan shutdowns at the best time with regard to production.

However, it can be costly in time and instrumentation. (58) At one extreme, some simple replaceable items can be checked visually at short intervals and at little expense, i.e. using traditional inspection routines which can be carried out separately or in conjunction with routine servicing. At the other extreme, complex replaceable items, eg. engines, might use spohisticated monitoring techniques such as vibration analysis or oil analysis, the cost of these techniques being justified by the high costs of repair and unavailability.

All condition monitoring/inspection' routines can be pre-planned and can be carried out as part of the preventive maintenance program and the resulting corrective work can be scheduled in the short term.

Opportunity Maintenance (3, 57, 58)

Opportunistic maintenance decides the repair/replacement of items neither on the basis of actual condition nor on elapsed time since last maintenance, but on calculation and probability evaluation of failure before the next repair period. The term is used for maintenance carried out during fixed-time or condition-based maintenance, but directed at items other than those that are the primary cause of the repair. The policy is most suitable for continuously operating equipment of high downtime cost.

Operation To Failure (57, 58)

No predetermined action is taken to detect the occurrence of failure or to prevent same. The corrective action that results occurs with a random frequency and with little or no warning.

Design-out Maintenance (58)

This concept aims to eliminate the cause of a maintenance requirement rather than to minimize the effect of failure. It is really an engineering design problem but it is often a maintenance department's responsibility. It is appropriate for areas of high maintenance cost which exist either because of poor design or because equipment is being operated outside its design specification but it can only be implemented if an information system exists which enable such high cost areas to be identified.

The choice to be made is between the cost of re-design and the cost of recurring maintenance.

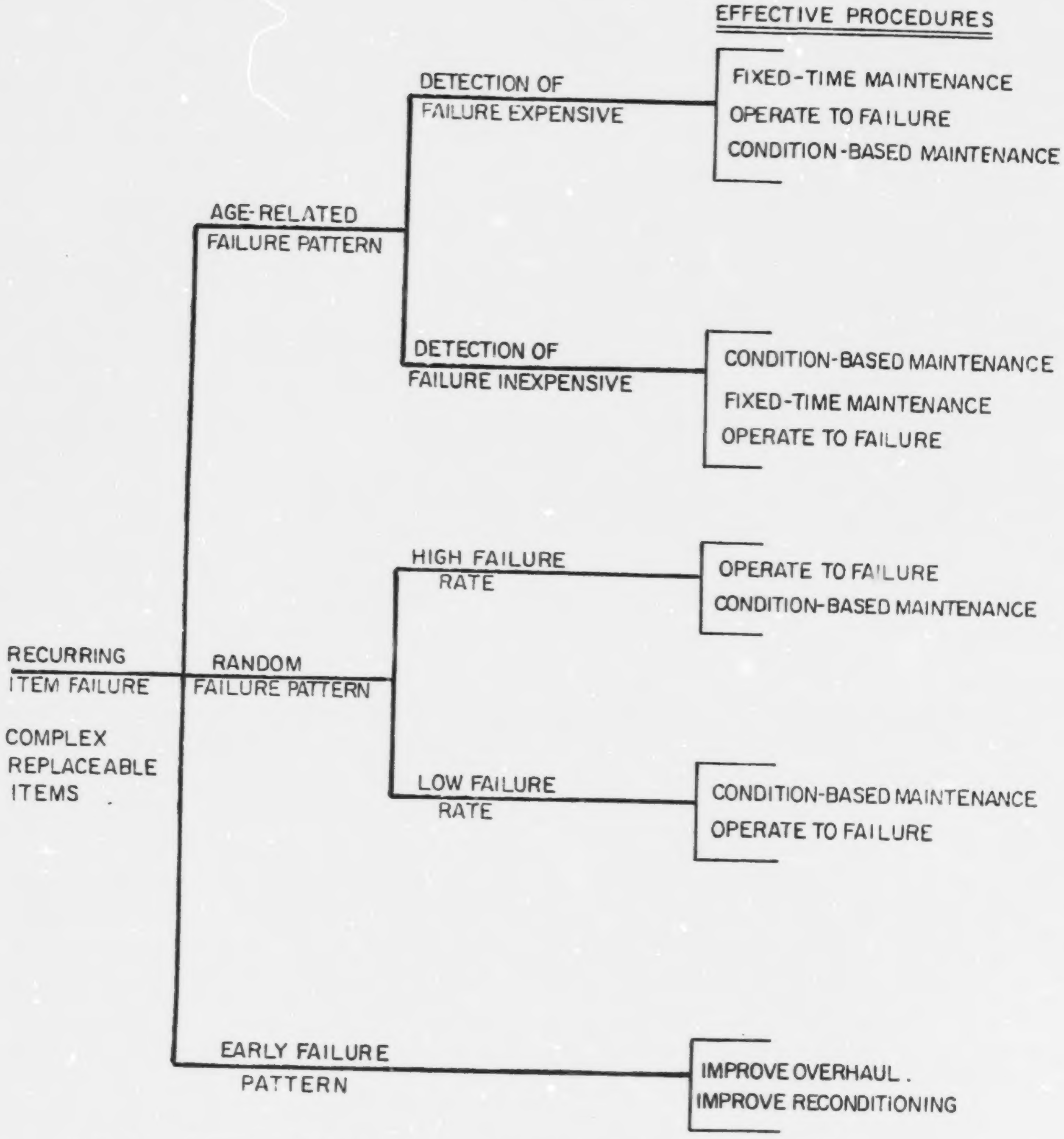
5.1.3 Formulating the Maintenance Plan

For a mining operation this should be built up by selecting, for each piece of equipment, the best combination of the actions outlined above (section 5.1.2) and then by coordinating those actions in order to make the best use of resources and time. The systematic procedures outlined in Figures 5.2 and 5.3 should assist in formulating the plan which should result in both a preventive maintenance program and corrective maintenance guidelines. The steps of these procedures will now be outlined.

Collection of Information

Ideally, preventive and corrective actions for each piece of equipment should be specified in some detail by the manufacturers. However, this is usually available only for simple replaceable items where maintenance is inexpensive; it is rarely provided for complex replaceable items where maintenance is very costly. (58) Therefore, accepting that there is some degree of uncertainty as to which combination of actions is "best", it is necessary to acquire all the information which might assist in the selection procedure. Information to be collected can be categorized as follows: (58)

1. Productive Factors: production pattern, nature of the process etc.
2. Economic Factors: consequence of failure, cost of replacement, cost of repair, material cost,


EFFECTIVE PROCEDURES
RECURRING ITEM FAILURE
COMPLEX REPLACEABLE ITEMS
AGE-RELATED FAILURE PATTERN
DETECTION OF FAILURE EXPENSIVE
FIXED-TIME MAINTENANCE
OPERATE TO FAILURE
CONDITION-BASED MAINTENANCE
DETECTION OF FAILURE INEXPENSIVE
CONDITION-BASED MAINTENANCE
FIXED-TIME MAINTENANCE
OPERATE TO FAILURE
RANDOM FAILURE PATTERN
HIGH FAILURE RATE
OPERATE TO FAILURE
CONDITION-BASED MAINTENANCE
LOW FAILURE RATE
CONDITION-BASED MAINTENANCE
OPERATE TO FAILURE
EARLY FAILURE PATTERN
IMPROVE OVERHAUL.
IMPROVE RECONDITIONING

Note: Appropriateness of procedures ranked in terms of cost and safety factors

Fig. 5.2 Formulating a maintenance plan - decision tree (57)

ITEM CATEGORY / PLAN	SIMPLE REPLACEABLE ITEMS	COMPLEX REPLACEABLE ITEMS	PERMANENT ITEMS	
			MAIN	SECONDARY
MAINTENANCE PROCEDURE	ADJUST/ REPLACE via F.T.M. or C.B.M.	REPAIR/ REPLACE via C.B.M or F.T.M. or O.T.F.	REPAIR via C.B.M.	NO ACTION
PREVENTIVE PROGRAM	INSPECTION ROUTINES LUBRICATION ROUTINES SERVICE PERIODS	CONDITION BASED ROUTINES OVERHAUL PERIODS	INSPECTION ROUTINES	NONE
CORRECTIVE POLICY	—	DECISION GUIDELINES DIAGNOSTICS CORRECTIVE METHODS	—	—
INVENTORY POLICY	CARRY MOSTLY ITEMS -SOME COMPONENTS- DEMAND PREDICTABLE	CARRY MOSTLY COMPONENTS -SOME ITEMS IN SPECIAL CASES- DEMAND DIFFICULT TO FORECAST	NONE CARRIED UNLESS INSURANCE SPARES	

C.B.M. - CONDITION - BASED MAINTENANCE
O.T.F. - OPERATE TO FAILURE
F.T.M. - FIXED - TIME MAINTENANCE

Fig. 5.3 Maintenance Guidelines (57)

monitoring cost, etc.

3. Equipment Factors: failure characteristics, repair characteristics, manufacturer's maintenance recommendations.
4. Safety Factors: internal, environmental and statutory regulations.

Such information having been obtained, it is then possible to identify critical units, forecast the maintenance load, appreciate the factors that constrain the selection of the best policy and therefore, construct a schedule for each piece of equipment involving minimum production loss.

5.1.4 Selecting the Maintenance Plan

The best combination of maintenance actions can be determined by first identifying the actions which are most effective and then deciding which is most desirable. The choice will depend on many of the above factors and will vary from one operation to another. However, the decision criterion should be minimum cost, given that safety criteria, statutory and otherwise, can be met.

The selection process must be applied separately to the different categories of items and the following is a summary of recommendations: (57, 58)

a) Fixed-time maintenance is usually most suitable for low-cost, simple-replaceable items. A detailed schedule of maintenance actions and frequencies is usually recommended by the manufacturer but this should be continually reviewed and upgraded as operating experience is gained. The large number of actions (for all the equipment in the operation) should be co-ordinated and then matched to scheduled downtime.

b) As illustrated in Figure 5.2, the failure characteristics (see chapter 8) of different items can be used to determine the most effective actions for complex-replaceable items; then the safety and cost factors can be used to decide on the desirable combination. The maintenance plan usually associated with complex-replaceable items is item repair through some form of condition-based monitoring although, in certain cases, operation to failure may prove to be the best plan.

c) Permanent items are best sub-divided into those that are expected to outlast the life of the equipment, and those that determine the life of the equipment. In the former category, and in the majority of cases, the maintenance plan is operation to failure, since failure is not expected to occur and therefore no pre-determined action is required. For items in the latter category, if deterioration is time-or-usage-based, condition-based maintenance is usually best.

d) All high-cost maintenance items, replaceable or permanent, should be considered for "design-out" maintenance.

5.1.5 What, When, How? (82)

Essential to the maintenance plan are clear and detailed descriptions of:

- what to maintain
- when to maintain
- how to maintain

a) What to Maintain?

The maintenance plan should cover all electrical and mechanical machinery in use at the mine. However, maintenance management should make two important observations:

- some equipment is more important than others
- some equipment is more reliable than others.

The plan must take these factors into consideration and allow for the constant maintenance of equipment that is essential to safety and production.

b) When to Maintain

The ideal frequency is one that eliminates breakdown. However, in practice, the operation must decide on suitable intervals based on such factors as experience, reliability of equipment, severity of duty, availability of time to do work, and the deployment of manpower.

Intervals must be realistic, especially in terms of available time to carry out maintenance. The plan must take into account and utilize natural stoppages in production, such as stops between shifts, backshifts, weekends, and holiday periods. On the other hand, production must co-operate to allow equipment to be made available for maintenance at these times. Once intervals have been fixed, the plan must include a "trigger" system to indicate when maintenance on a particular piece of equipment is due.

c) How to Maintain

The plan must indicate the extent of work expected for each type of maintenance action. The craftman should be told in detail what is required and not left to do what he thinks ought to be done. This is usually achieved by the use of checklists which should be prepared for almost every piece of equipment in the operation and should list checks to be made in convenient groups.

For example, (82) in the U.K. coal mines, checks are grouped under such headings as "A examination", "B examination", etc. An "A examination" usually involves fairly simple checks that demand no dismantling of equipment, minor adjustments, tightening nuts, checking oil levels, etc. This group of checks is usually equivalent to running maintenance. A "B examination" is more involved and a "D examination" might be a complete overhaul in the workshop.

Each examination is clearly defined in the checklist. Thus when a craftman is instructed to make a "B examination", he knows exactly what has to be done.

5.1.6 The Final Plan

The final maintenance plan must be a combination of a preventive maintenance program and corrective maintenance guidelines.

The preventive program must include, for each unit, compulsory preventive routines, inspections, services and, when necessary, complete overhauls and other major preventive work. In general, such work should be designed to be carried out without interfering with production: either as running maintenance or when a unit is not required by production. The advantage of preventive maintenance is that it is predictable, can be planned in detail, and is there to control the level of corrective maintenance. If maintenance is regarded as a pool of resources aimed at controlling availability, then the preventive program gives the maintenance manager his main means of control.

The most recent advance in mine preventive maintenance is known as the "unit change-out system" (82) in the U.K. and as the "subassembly system" (35) in South Africa. The "unit change-out system" is an integral part of the contract maintenance program employed by the National Coal Board in the U.K. (82) The "sub-assembly system" is incorporated into the daily on-the-job maintenance program at the gold and coal operations in South Africa. (35) The systems are strikingly similar, involving rather large initial capital outlays but showing substantial decreases in equipment downtime once the program gets underway. The success of these programs depends on five major factors:

1. Organizing the program
2. Evaluating units to determine, within safe limits, the average life of various items
3. Supplying adequate spares and replacement parts
4. Allocating a sufficient number of men to carry out the program
5. Keeping an accurate record of each equipment item.

Even allowing for the most effective preventive maintenance program, failures will still occur and some priority must be given to corrective maintenance guidelines.

The disadvantages of corrective maintenance are the loss of production and the difficulties of planning due to the random nature of failures and repair times. The dynamic nature of corrective maintenance provides the most difficult aspect of maintenance planning. However, the existence of a sound preventive program helps to indicate the sources and nature of corrective work and allows the maintenance manager to identify and concentrate on, those critical units. This is particularly important in a new operation because of the difficulty of predicting the level of corrective maintenance. (56)

The result of the maintenance plan should be a corrective maintenance strategy for each item, and corrective guidelines for those considered critical. Even allowing for uncertainty, this should be of considerable assistance in planning and handling the corrective maintenance load.

Although there is no universally appropriate mine maintenance plan, it is imperative that the functional relationships illustrated in Figure 5.4 be basic to all maintenance plans. The concepts in this figure can be used, in conjunction with consideration of other influencing factors, to develop and establish the most appropriate maintenance plan for a particular situation.

5.1.7 Safety Considerations

No maintenance plan is complete without serious consideration of safety. Every plan should ensure that safety action is taken before, during, and after the maintenance action.

The past two decades have seen increases in both the size and complexity of mining equipment. Doubtless, this trend will continue and will involve people in repair, maintenance and supervision; in carrying out these functions conditions will differ from normal operating conditions and accidents will occur unless rigid safety procedures are in place. Two essential safety aspects should be addressed in the maintenance plan:

- maintenance-safety testing for the complex machinery

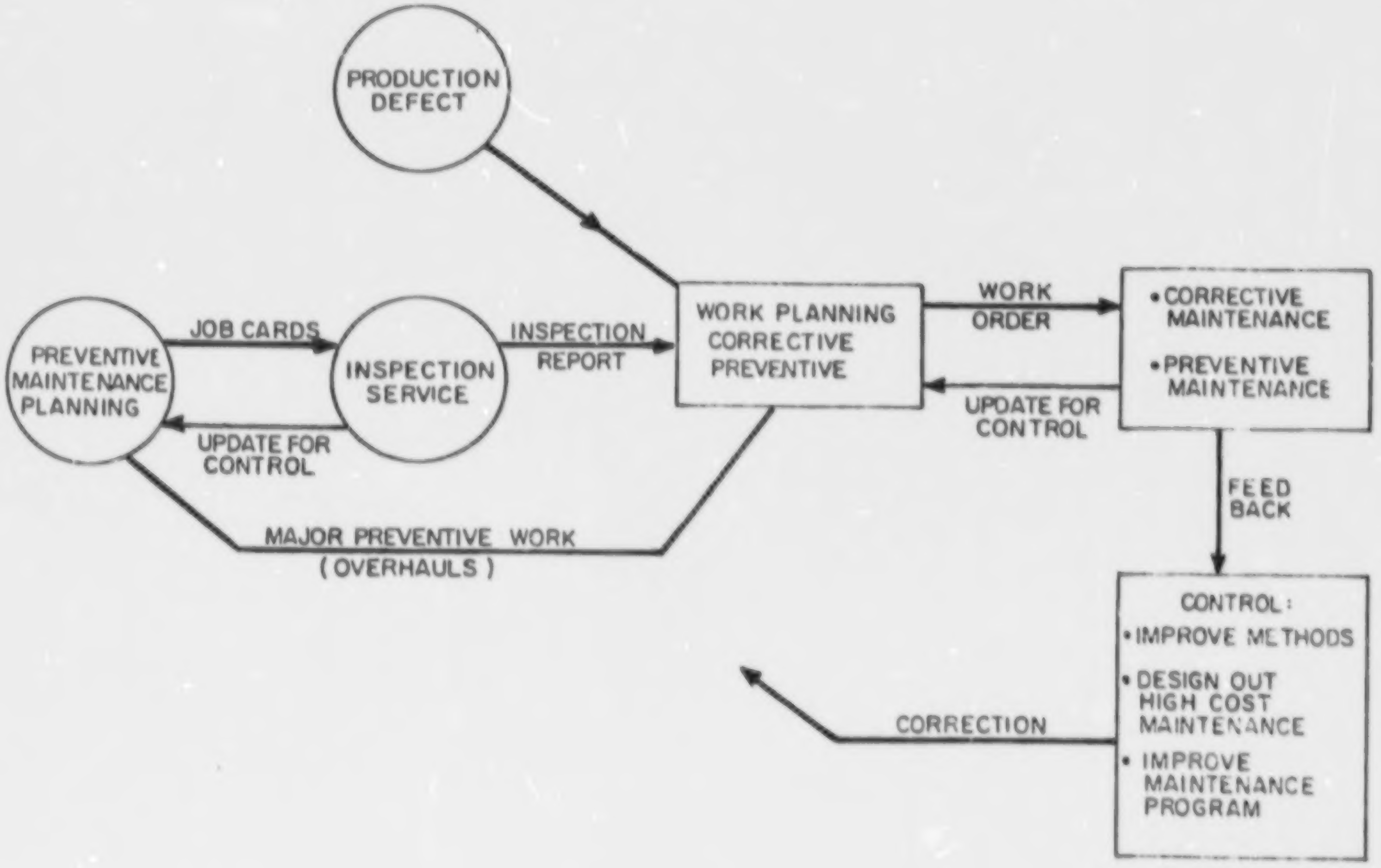

PRODUCTION DEFECT
PREVENTIVE MAINTENANCE PLANNING
JOB CARDS
INSPECTION SERVICE
UPDATE FOR CONTROL
INSPECTION REPORT
WORK PLANNING CORRECTIVE PREVENTIVE
MAJOR PREVENTIVE WORK (OVERHAULS)
WORK ORDER
UPDATE FOR CONTROL
• CORRECTIVE MAINTENANCE
• PREVENTIVE MAINTENANCE
FEED BACK
CONTROL:
• IMPROVE METHODS
• DESIGN OUT HIGH COST MAINTENANCE
• IMPROVE MAINTENANCE PROGRAM
CORRECTION

Fig. 5.4 A functional maintenance diagram (57)

now in use (61)
- working conditions safety for the protection of maintenance personnel.

Maintenance Safety Testing (61)

While it is the primary function of maintenance management to ensure that equipment is regularly serviced, to keep it operative and its components in working order, it is also responsible for establishing a system of maintenance safety testing which ensures that equipment, both fixed and mobile, is kept at standards suitable for the duty involved. It has been a matter of concern for some time that, while mining equipment is serviced regularly to ensure continuous working order, there has been little practical testing to prove its safety effectiveness.

A survey (61) carried out by the HM Mines and Quarries Inspectorate (U.K.) in 1977 revealed the following hazard areas:

1. For large mining equipment, braking efficiency must be given serious consideration. Brake performance for both rubber-tired and tracked units should be measured periodically as well as after service or repair.
2. Hydraulic equipment has an apparent advantage in operating efficiency but there have been incidents of fire due to failure of components such as pipes and hose lines. In a number of cases high pressure fluids, near diesel engine exhausts, have ignited and burned out a machine. The components of hydraulic systems should be compatible with the duty of the machine and fire-fighting equipment should always be available. In the long term, the use of fire-resistant fluid should be considered, also the use of remote fire-fighting equipment similar to that used in aircraft.
3. Defects associated with machine structures - cracks associated with welds and weld repairs - can go unnoticed, in the absence of thorough examinations and can result in fatalities. All machines subjected to arduous duties must have a

> formal process of examination of their structures, based on established techniques and carried out at intervals compatible with the age and duty of the machine involved.

The survey clearly showed that large, complex machines cannot be expected to operate safely without a sound, practical system of maintenance safety testing.

There can be two main approaches to applying maintenance safety testing: either test equipment to ensure that it is within established standards (as intended by the manufacturer) or test to standards set by the operation involved. The latter is not recommended since tests related to local circumstances will have to be made relative to changing conditions and so there will be no real basis for them. Moreover, testing and use for local conditions may introduce liability hazards that may not be reasonable for the operation.

Working Condition Safety

Procedural safety and a safe working environment must also be an integral part of the maintenance plan. Maintenance management should not merely pay "lip service" to safety; it should put sound practices into effect. Safety should be a part of every maintenance manager's job.

Safety consciousness will develop among tradesmen only if it is preached and encouraged by maintenance. The maintenance department should ensure that:

1. All maintenance work is carried out in safe physical surroundings.
2. A safety program is in place, making full use of such measures as posters, signs, inspections and meetings.
3. All personnel are provided with safety apparel including hat, glasses, clothing and footwear.
4. All tools and equipment are in good order and equipped with the necessary safety features.

To a great extent it is the company's responsibility to create a safe working environment for all its employees. However, maintenance has its own responsibility in this regard and the maintenance plan should allow for the development of a comprehensive safety program.

5.2 Planning and Scheduling

Essentially, planning and scheduling are decision-making processes and, as such, must be integral parts of the maintenance management program. In the maintenance context, planning means the organizing of resources to carry out a specific job effectively. It should define how a job is to be done, by whom, and in what sequence of steps. Similarly, scheduling should provide a job's place along a time scale defining when and where it is to be done.

Maintenance planning and scheduling should always be directed towards: (104)

- minimizing idle time of the workforce
- maximizing the efficient use of work time, material, and equipment
- maintaining equipment at a level that is conducive to the needs of production.

Although planning and scheduling are essentially different functions, it is very difficult to separate them and, in many programs, both functions are performed by the same individual. (69)

Because planning and scheduling are essential parts of the maintenance program, they must be consistent with the objectives, policies and procedures of that program. It is only against such a background that these functions will be of any benefit to the maintenance organization. However, regardless of the background against which the planning and scheduling functions are to be established, the following principles must be adhered to: (104)

- they are only valuable when their returns exceed their costs;
- they must always be flexible to allow for frequent

changes in the program;
- they must be built on the development of good procedures applied by skilled personnel.

The planning and scheduling procedures are only the first and second steps respectively in a threestep process. Execution of the plan according to the schedule is the third and final step.

5.2.1 Maintenance Planning

Maintenance job planning is, in effect, the engineering of the work order and the extent to which the work order is engineered is determined by the nature of the job request. The work order must supply sufficient information to allow the planner to determine the complexity of the job, the materials required, and the magnitude of the effort required to complete the job. As noted in an earlier section of this text, maintenance jobs can be introduced into the system in a number of ways but regardless of how the job request gets into the system, its implementation should be planned to some extent.

It is the planner's major activity to prepare job details so that the job can be executed smoothly and effectively. Basically, the planner's duty is to provide plans and procedures to such maintenance actions as PM inspections, lubrication, overhauls, project work and any other planned activities. These planning actions include job organization, labour estimation, identification and obtaining of materials and coordination of work with production. In addition, the planner should monitor the conduct of PM inspection and analyze repair history to convert the results into planned maintenance work. The planner should confine his activities to planned maintenance work and leave unscheduled and emergency work to maintenance supervisors.

Although many organizations use the planner as a planner-scheduler, this may not be the best strategy. According to Tomlingson, (104) the planner cannot act as a scheduler because the scheduling activity is complex in itself. Scheduling can only be effective if it is done jointly between maintenance and production. Moreover, Tomlingson also stresses that the planner may investigate the best scheduling time for a job but he cannot do the scheduling himself. He can only recommend. In certain instances the planner may schedule such routine activities as inspections and lubrication but generally, he should be independent of the scheduler though working in close cooperation with him.

On the other hand, maintenance planning is not exclusive to the maintenance planner. For overall effectiveness, the following personnel should also be involved at one stage or another: (55, 104)

- the tradesman
- the foreman
- the superintendent/manager
- the operations manager.

Review and revisions by these personnel, subsequent to the actions of the maintenance planner, will better assure the achievement of the desired results.

The Planning Procedure

For the planning activity to be successful, there are certain vital elements that should be carried out according to specific procedures. These include: (104)

Job Scope	-	What does the job involve? What resources (human and material) must be organized and controlled?
Timing	-	Job starting time? Job completion time? Time available for planning the job?
Priority	-	Urgency of the job? A priority system should exist. Priorities are best assigned, according to the established system, by operating personnel. How does priority affect the timing of other jobs?
Approval	-	Who will approve the job? Who will approve the plan?
Cost	-	What will be the cost (material and labour) of the job? How will it be determined? Is there a cost centre for the

job?

Labour - What trades are involved? How many manhours are required? What estimating techniques are best? Are there established job standards?

Material - What materials are needed? What quantity? Are direct charged items required? How much lead-time is needed for these items? Are the stocked items available in the stores? What are the charge-account, item and location numbers? How will material get from stores to the job site?

Tools - What special tools are needed to execute the job? Where can they be obtained?

Equipment - What special equipment is needed to get job done? Is such equipment available or must it be rented?

Safety Instructions - What special safety needs must be met?

Job Instructions - How will job be done? Are sketches/drawings to be followed?

Job Control - Who are the supervisors (front-line) to be involved? What degree of control is to be exercised?

Reports - On what will job progress be based? From what sources must information be drawn? What reports are required?

Work Orders -How many separate work orders will be needed to cover all phases of the job?

All of these elements must be considered in any well-planned job; the degree to which each element is applicable is dictated by the scope of the job.

Planning Techniques

During the planning process of a specific job, a single planner can be called upon to handle a variety of tasks. Each of these tasks may be in a different stage of the planning process. To ensure that the planner is able to "manage" all the work orders simultaneously, a reliable method of controlling work orders from stage-to-stage is necessary. A very effective technique for achieving this control is the use of Work Control Racks or as sometimes called, Work Order Loading Boards. (104) These are usually slotted to illustrate such designations as:

- assigned work orders
- completed work orders
- incompleted work orders.

In some cases, racks are designated for such purposes as "material needed" or "fabrication needed". Regardless of the number of slots used, they must be placed in the sequence which follows the planning steps.

The use of loading boards or racks facilitates the work of both the maintenance planner and foreman. When a planner completes the engineering of a work request, he places it in the allocated slot of the loading board. This slot is usually divided into sections, each section being assigned to a particular foreman. At the beginning of a shift, each foreman checks the board and removes those orders that have been assigned to him. At the end of the shift, completed work orders are placed in the "completed order" slot. If for some reason certain assigned orders were not completed, these are placed in the appropriate section of the "incompleted order" slot. Thus, both the foreman and the planner have some degree of control over the flow of work orders. Moreover, when a planner looks at his loading board, he gets a very good picture of his work load, backlog, and the nature of the backlog.

Many other techniques are available to the planner for sequencing the various steps of planned jobs. The most useful are: (69, 84, 104)

Bar Charts - These list actions against time shown in a chronological order.

Gantt Charts - These show the time relationship of job actions occurring simultaneously or chronologically.

Critical Path Method - This technique identifies the shortest elapsed time for completing specific actions of major projects (see Chapter 8).

The above planning techniques apply equally to major maintenance jobs as well as to project work such as installation, modification or equipment construction.

Standard Planning Procedure (104)

To enable the reader to understand the most effective role of the maintenance planner, a standard procedure is described below:

Procedure: The maintenance planner uses the work order to identify specific planned jobs. The scope of each job is analyzed and a job plan is prepared. The job is reviewed in the field (mill, pit or underground), procedures checked, materials identified, trades identified and manhours estimated. As necessary, instructions (job and safety) are provided. All these activities must be performed in close liason with the front-line supervisors. When job approval is obtained, the planner sequences work orders with other planned jobs pending scheduling.

Planning can have a significant effect on the efficiency with which maintenance actions are carried out. As the planning activity improves (more and better planned jobs), less manpower is required for emergency work and as a result, better use is made of manpower. Thus, the same workforce is able to perform more work.

5.2.2 Maintenance Scheduling

Many mining operations have experienced great difficulty in developing schedules and in performing to them. In reality, scheduling is simply a matter of developing schedules and having adequate manpower to perform the work on schedule. (85) Good long-range planning and equally good manpower planning are the primary requirements. (85)

In today's mining environment, maintenance scheduling is becoming more and more difficult because of the large number of pieces of equipment and the even larger number of daily job requests. Manual scheduling is virtually impossible so use of computer can yield significant benefits.

Maintenance scheduling is primarily concerned with arranging the sequence in which the work orders will be worked. However, it is not exclusively a maintenance function. Planning is a maintenance function in which certain steps, such as work approval and priority-setting, require production participation. However, scheduling must be a joint maintenance/production venture and should never be done by maintenance alone when production equipment is involved. Successful scheduling requires the acknowledgement that the activity must be a two-way street. If production is not made aware of maintenance plans to work on equipment, equipment simply will not be made available and schedules will not be met.

Effective scheduling must be centred around the following: (69, 104)

Equipment - equipment must be made available at the best time for all parties concerned; duration must be long enough to get the job done - and done well.
Material - the system must provide some means of locating and receiving materials for the time at which the job is to be done; materials must be on hand (preferably on job site) to ensure minimum delay.
Labour - the right skills in the proper quantity must be in place.
Standards - the role of standards in scheduling is as important as in planning; standards must include estimated number of manhours required to perform the job; manhours estimate is the main scheduling guide.
Priority - the system must ensure that the most needed jobs are performed first; a pre-established priority system is most important.

Superimposed on the above constraints must be the desires of operating personnel, which might change from day to day or even shift to shift.

Scheduling should always be based on what is realistically likely to happen rather than on what the scheduler would like to happen. Constant liason with operating personnel helps in this regard. This is best achieved through regular scheduling meetings between maintenance and operating personnel at which potential problems are identified, discussed and agreements reached.

A well planned maintenance job stands a very good chance of being carried out efficiently. However, unless all of the resources are properly scheduled, the benefit of good planning is lost. In brief, proper scheduling is essential to getting maintenance jobs done on time and within cost limits.

Scheduling Techniques

The scheduling activity must cover all the different types of maintenance work. These include:

- routine work; lubrication, inspection
- preventive work; inspection/replacement
- emergency work; unscheduled repairs
- overhaul; specialized preventive work.

Each of the above classes of work has a slightly different technique, but all are built on the same principles.

a) Scheduling Routine Work

As the name implies, routine work includes all servicing that is done on a regular basis. Most operations lay down rules (procedure and frequency) for performing routine work. For example:

- check all pumps first thing every morning
- lubricate trucks daily (or weekly)

- all motors are to be inspected first week of every month.

Thus, routines are established by defining the amount of time available for work, the number of units in a given period and the type of work to be done at a specified time. In most cases a cyclic pattern is established - work can be repeated over and over again with little need for additional instructions.

Routine services usually include lubrication, checking, inspection and adjustment. They are all relatively simple to schedule and the following steps are taken to facilitate the process: (69, 84)

1. The use of "blanket work orders" to simplify instructions.
2. Pre-prepared checklists to guide service-men.
3. Estimating job times to determine the period of a complete cycle.
4. Establishing job frequencies based, initially, on manufacturer's recommendations but improved as experience is gained in such areas as equipment work-load and equipment working conditions.
5. Grouping equipment with similar procedures and frequency of inspection.

For routine maintenance work, therefore, once a sequence of steps is established, work proceeds practically by itself.

b) Scheduling Preventive Work

Preventive maintenance work, by its very nature, is usually scheduled with a time range in which the work should be done. PM scheduling is usually dictated by one or more of the following: (7, 82)

- Elapsed time - in weeks or months.
- Operating time in hours or days.
- Tonnage handled or produced.
- Inspection.

- Personal judgement.

Each of these techniques has its supporters among maintenance managers however, a combination of inspection and operating hours or tonnage produced seems to be the most popular. Where the number of units is large, on the other hand, the elapsed-time technique seems to allow more flexible scheduling, allowing time to get around to all the equipment.

Scheduling of PM work, regardless of the technique used, should always be done with the following principles in mind: (69, 104)

1. Minimized downtime - which should be less than that brought on by emergency maintenance.
2. Level of PM work relative to the total maintenance load - PM work should predominate
3. Time for performing PM work - best on day shift since supervision manpower are greatest at that time.

Although PM scheduling is similar in many respects to the scheduling of routine work, a major problem is usually encountered - what is the best or optimum interval (operating hours, weeks, days) to schedule the maintenance actions? A technique known as "defect analysis" (34) provides a solution in this regard.

Defect Analysis

The technique of defect analysis is based on the development of an item's standard lifetime and comparison of this with its actual lifetime. Standard lifetime is the period that should elapse before an item or component suffers from a given kind of deterioration and fails and must be known to determine when maintenance is required. This is usually determined by experience in an on-going opeation. Comparison of the standard and actual lifetimes will indicate components' failure or deterioration rates. By dividing the standard lifetime by the actual lifetime, a defect quotient is obtained and the larger this defect quotient, the higher the failure rate of the component. Collecting these defect data helps maintenance to keep up to date on preventive maintenance needs.

A well-designed form can be used to record such information as the number of occurrences of various defects, manhours required for repairs, breakdown hours involved, whether the defect was caused by the operation, the maintenance proces or the environment, and whether the defect can be controlled by preventive maintenance. Such defect records enable maintenance to pinpoint components that are deteriorating and need attention to prevent breakdown, accidents, and lost production. The combination of standard lifetime data and the identifiable-defects history can then be used to set up preventive maintenance schedules.

In setting up a system based on defect analysis the following steps should be followed: (34)

1. Review all data collected and prepare an overall PM schedule covering all equipment.
2. Based on overall schedule, develop separate job cards for each piece of equipment. Information on each card should include:

    - equipment identification
    - service/inspection steps
    - a "defect limit"
    - inspection frequency
    - trades and number of workers
    - estimated time for each task.

Cards should be small enough to be carried around and should be protected (plastic covering) to allow repeated use.

Controlling the scheduling of PM work need not be complicated. A simple card index system, eg. a "tickler file" or a "revolving card file" can be used as memory core to initiate or trigger inspections. (7) Moreover, the steps described can be recorded and controlled manually, though, for larger operations, a computer will greatly facilitate the process.

c) Scheduling Emergency Work (55, 69, 82)

There is no formal technique for scheduling emergency work; the primary objective should be to minimize its occurrence and, when it does occur, to keep the time to execute it to a minimum.

Emergency work has special significance. Whatever resources are required to handle an emergency should be readily available, nearby, or be sent to location immediately. In a number of operations, emergency work is initiated by telephone or some other form of verbal communication for expediency. The formal work request follows after the work is in progress. Other operations maintain an emergency manual that includes pre-planned work orders for a number of emergencies that might occur.

In practice, emergency work is not a part of the maintenance work schedule since it is usually initiated by production. However, it does affect maintenance schedules and therfore allowance must be made for its inevitable occurrence. Maintenance schedules must always be flexible enough to cater for emergencies.

d) Scheduling Overhauls (69, 82, 106)

An overhaul is really a specialized kind of PM action and as such, the same five factors (see section b) that are used to dictate PM scheduling are applied to the overhaul action. However, an overhaul usually involves a higher number and a wider variety of maintenance tasks than routine PM work and is usually scheduled at longer intervals (quarterly, semiannually or annually).

Once planning is adequate (job-material listing, time estimation), overhaul scheduling is really not difficult. The GANTT chart or the conventional bar-chart is still the most popular technique used. For more complicated operations, techniques have been made more attractive with the advent of the computer. Today, a large number of package programs are available from management consultants and software manufacturers.

Like routine PM actions, determining the optimum or economic interval for overhauls is still done subjectively in many operations - based purely on experience. While this strategy may be acceptable, it can result in undermaintenance or over-maintenance of equipment, and both can be costly. A technique known as "principle of simultaneous downtime" (POSD) has proven particularly beneficial at a number of US energy research facilities. (41)

The Principle of Simulaneous Downtime (PSOD) (41)

The principle of this technique is quite simple: component failures are synchronized to occur as nearly simultaneously as possible, thereby minimizing the occurrences of overhaul-downtime. The technique is particularly suitable for maintaining large, expensive equipment items with high downtime costs.

The basic procedure for applying the principle of simultaneous downtime is:

1. Breakdown repair records are sorted according to failure item.
2. Records of each type of failure are arranged chronologically.
3. Times between failure for each type occurrence are calculated.
4. Average times, and the longest and shortest times, between failures are also calculated.
5. Results are talulated as illustrated in Table 5.1.
6. Data is then analyzed so that decisions about synchronized failures can be made.

From the information revealed in Table 5.1, components 2, 3, 4, 5, 6, 7, 8, and 11 should be synchronized because:

- Variations of high, average, and low times between failures are very small

Table 5.1 PSOD Analysis Chart (41)

		Time between failures (months)			Repair Hours	Cost Ratio: Downtime/Repair
No.	Component	High	Average	Low		
1	Liner A	10	4	2	336	3.4
2	Liner B	4	4	4	280	7.0
3	Liner C	4	4	4	200	6.7
4	Insulation A	4	4	4	150	15.0
5	Insulation B	4.1	4	4	125	17.9
6	Insulation C	4	4	4	80	13.3
7	Burner A	4.2	4	4.1	16	40.0
8	Burner B	4	4	4	8	53.3
9	Burner C	8	6	5	4	4.0
10	Cooler A	12	4	3	40	10.0
11	Cooler B	4.5	4.2	4.3	30	30.0
12	Cooler C	17	5	6	10	12.5

Note: The kiln data above is purely hypothetical.

- Ratios of downtime costs to repair costs are very high.

The decision to synchronize failures is usually difficult because of the variations in time between failures of the many components. Careful study of failure times, repair cost, downtime cost, and the ratio between these costs is necessary. Another consideration is whether a component failure will cause serious failures of other parts and create safety hazards. If it will, the repair should be done during the planned shutdown. Very often, instrumentation is installed to give advance warning of failure.

5.3 Conclusion

The maintenance plan provides the maintenance management program with its overall objective - what to maintain, at what time interval and in what manner. It spells out the service to be provided by maintenance to the production sector.

On the other hand, planning and scheduling supplement good organization by ensuring the accomplishment of maintenance tasks, according to specifications and in a specified time frame, thus allowing minimum production downtime due to maintenance.

It is the combination of these two elements that gives the administration control over day-to-day maintenance activities. Moreover, it is only when this combination has been achieved that maintenance is performing the greater part of its work at a determined rate in a prescribed and measured manner. That situation also assumes the conditions for minimum emergency maintenance.

Chapter 6

INFORMATION SYSTEM AND CONTROL

Effective operation and control of the maintenance management program rests with a good information system. A maintenance manager need not know all the details of his maintenance operation, but he needs to know at least the pattern of the activities under his control. For this, he must have adequate and reliable information available to him.

In addition to its use by the maintenance manager, information is also essential to all other levels of management. In a sense, information is the binder that holds the maintenance system together. It must provide the administration with the basis for taking those actions which ensure that the objectives of the maintenance program are met. It must allow maintenance: (104)

- to determine what must be done
- to justify actions and their timing
- to measure actions' effectiveness.

A well-designed information system must provide maintenance with answers to a number of questions, including: (62)

- What is the level of manpower utilization?
- What are the labour and material costs?
- What is the percentage of backlog?
- What percentage of time is spent on emergencies?
- What is the level of overtime?

Answers to these and other questions should be provided in well formulated reports based on information generated by the system. Sources of information include work orders, material requisitions, and time cards. Other sources include production and accounting reports.

6.1 Essential Elements of the Information System

A good information system must respond to the needs of maintenance. To achieve this, four elements of information collection are essential.

(a) Data Acquisition: Enough data should be collected to allow the maintenance manager to have effective control over the maintenance operation. However, data collection can be expensive, especially in a manual system, so only data that is helpful should be acquired. In most cases, a manager is only interested when something is out of line - when costs are too high, when spares will not be available or when overtime is getting out of control. The system should be designed to collect the basic information that will give indication in areas like these so, careful consideration must be given to the information required out of the system. Unnecessary data must not swamp the system but, at the same time, the system must be capable of producing the essential answers.

(b) Data Organization: A uniform method of compiling data must be adopted to allow for a systemized presentation. Data must be presented to reflect the variability of the factors which are to be controlled and it must be assembled so as to be meaningful to the user.

(c) Data Distribution: To be effective, information must be allowed to flow through the organization and a well-organized reporting procedure is the only effective way of achieving this. Reports needed for control of the maintenance operations include:

- Labour utilization
- Labour scheduling
- Equipment downtime
- Work order backlog
- Cost
- Inventory.

Much of the information presented in these reports should become part of the historical data record system.

(d) Data Feedback: Information must be fed back into the system to aid maintenance decision-making and to effect improvement to aspects of the management program.

Regardless of whether a manual or a computerized program is employed, the same basic information is needed for effective maintenance control. The only differences are in how the information is handled and what use is made of it.

Essentially, information is the substance that not only holds the maintenance program together, it also makes the maintenance organization run. (104)

6.2 Maintenance Control

The maintenance management program which, so far in this report, has tended towards maintenance-action planning, must also be concerned with maintenance control. In the previous section (6.1), the importance of information was emphasized, but it is not sufficient, merely to collect information. The primary purpose of information is to gain control of activities. Once in the hands of the decision-maker, it must be used to determine the action required. Once the action gets underway, it must be controlled and as the action is completed, its effectiveness must be measured. (104)

The maintenance manager needs to set up the framework that will provide him with the means of exercising control over his department's activities. The best controls are not necessarily the elaborate ones; very often, the simpler the control procedure, the more useful it proves to be. An elaborate procedure will usually better serve a large, complex organization. Whereas, the small operation can achieve satisfactory controls in a simple way so long as all the ingredients of a complete control cycle are involved.

The complete control cycle includes: (84, 62)

- adequate information reflecting the behavior of

operations
- comparison of results with pre-set targets
- appropriate corrective action.

How does this apply to maintenance? Maintenance must control those aspects of its activities that are most important in achieving its objectives including:

- productivity; all cost items
- downtime
- quality.

It is the combined control of these aspects of maintenance activities that enables an operation to control its costs. (see Figure 6.1) Essentially, maintenance has very little direct control over costs; its control is limited to the efficiency with which it controls these three areas.

6.2.1 Productivity Control - Monitoring

Necessary to productivity control is the use of indexes (as indicators) to reflect and gauge the ability of maintenance to perform as required. In maintenance terms, productivity is the ratio between some measured aspect of an activity and a standard for the resources to be consumed in completing that activity. The many factors that measure the various aspects of maintenance can, in some way, be related to acceptable standards and so, indexes can be used to relate actual performances to planned efforts. In such cases they establish useful measures of maintenance productivity.

Maintenance-productivity indicators fall into three categories: (68, 104)

- maintenance effectiveness
- maintenance service
- overall program performance.

In most programs each management-level of the organization uses its own unique indicators to assess the performance of those elements it controls. For example, (68, 104) the frontline supervisor is interested in indicators that tell him the total idle time of his crew or whether or not

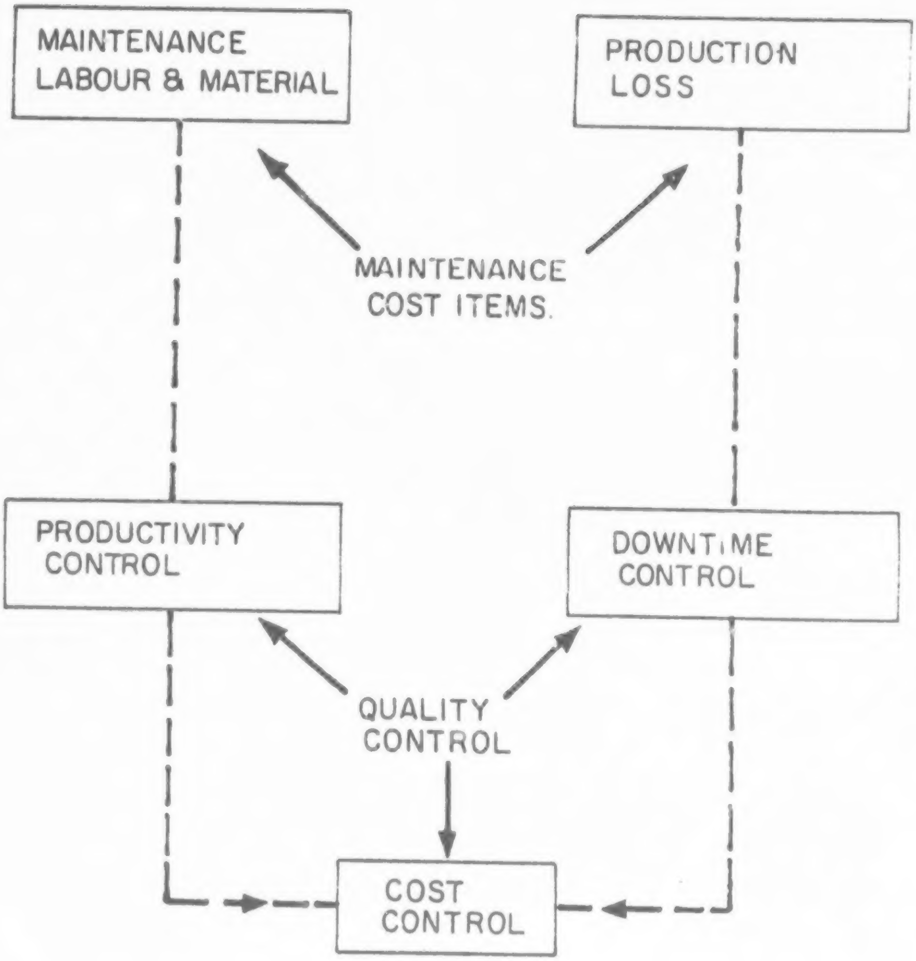

MAINTENANCE LABOUR & MATERIAL
PRODUCTION LOSS
MAINTENANCE COST ITEMS.
PRODUCTIVITY CONTROL
DOWNTIME CONTROL
QUALITY CONTROL
COST CONTROL

Fig. 6.1 Aspects of maintenance control (38)

craftmen complete jobs on time, using the resources allocated. The middle manager is much more interested in such indicators as the ratio of scheduled to completed work orders. Upper management is interested in percentage overtime, expenditures and overall performance. Because of these differences, a number of indexes must be adopted to give a complete status of maintenance productivity.

The number and types of indexes used in a particular program is up to the organization involved. (See listing in Table 6.1) However, regardless of these differences, indexes must be applied consistently and over a long enough period of time to develop meaningful trends. Trends are much more meaningful than absolute values in maintenance control, so it is the continuing comparison of derived indicators (indexes) with existing historical data that provides maintenance with the information to effect control.

6.2.2 Downtime Control

Downtime control is directly related to production loss and it is essential, in conjunction with productivity and quality control, to the achievement of minimum maintenance cost. Downtime control is achieved through a repeating "downtime improvement cycle" (DIC) (38). Each time the cycle is repeated, the level of downtime in a system is reduced. (see Figure 6.2)

A DIC consists of five basic steps as follows: (38)

1. Categorizing equipment by criticality and writing PM instructions appropriate to the criticality. Criticality determination is an essential step in the cycle since a DIC may involve many parts, machines, and problems. Only after criticality is determined should efforts be applied. Factors to be considered in determining criticality:

    - dollar value
    - function
    - frequent maintenance problems.

    Once the criticality coding system is set-up, PM

Table 6.1 List of Common Productivity Indicators (68, 104)

a) Indicators Use By Planning
  - Actual manhours versus estimated manhours
  - Actual cost versus estimated cost
  - Percentage productivity as measured by work sampling
  - Staff as a percentage of total number of maintenance employees
  - Percentage of manhours spent on scheduled work
  - Percentage of available manhours spent on breakdown repairs
  - Number of work orders completed as a percentage of total number issued

b) Indicators For Control Of Work Force
  - Percentage overtime
  - Downtime
  - Backlog for entire work force
  - Percentage of maintenance work included on work orders
  - Percentage of manhours which has been planned
  - Percentage of PM work
  - Material cost versus labour cost
  - PM hours versus total maintenance hours

c) Indicators For Monitoring Entire Program
  - Total maintenance cost
  - Maintenance cost versus production cost
  - Production losses caused by maintenance
  - Maintenance cost per unit of production

d) Indicators For Assessing Maintenance Service
  - Equipment running time versus scheduled operating time
  - Average equipment running time between repairs
  - Frequency of breakdown
  - Severity of breakdowns
  - Cost of breakdowns versus total production cost

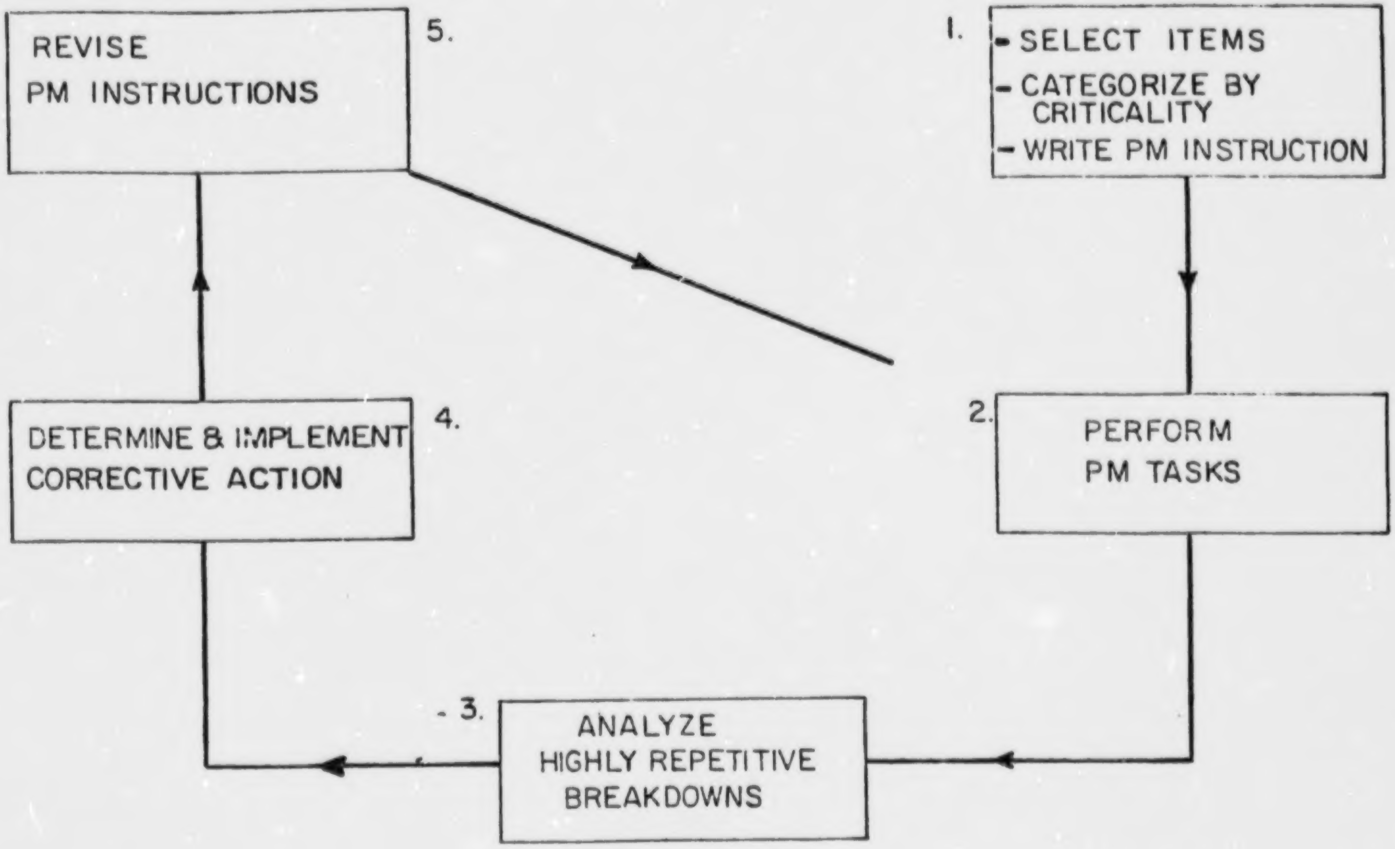

5.
REVISE
PM INSTRUCTIONS
1.
- SELECT ITEMS
- CATEGORIZE BY CRITICALITY
- WRITE PM INSTRUCTION
4.
DETERMINE & IMPLEMENT
CORRECTIVE ACTION
2.
PERFORM
PM TASKS
3.
ANALYZE
HIGHLY REPETITIVE
BREAKDOWNS

Fig. 6.2 Downtime improvement cycle (D.I.C.) (38)

efforts should be apportioned accordingly. Such effort will be in the form of

- PM labour and material
- engineering analysis
- systems and procedures.

2. Performing PM
3. Recording equipment/parts breakdowns (failures). Breakdowns are usually classified by equipment-type to facilitate the identification of highly repetitive failures. Equipment/parts failure records are very important.
4. Analyzing highly repetitive failures.
5. Determining and taking corrective action. Such action may include one or more of the following:

    - correct operational abuse
    - replace poorly selected equipment
    - correct previous faulty repair
    - revise PM instructions
    - redesign/modify equipment.

6.2.3 Quality Control

Maintenance operations are becoming more aware of the benefits of a well-planned maintenance quality control program. (108) It can improve the maintenance function, improve service to production, increase personnel efficiency, and most important, reduce maintenance costs. Mine managers must recognize the value of quality control and what it can mean to the mine maintenance operations. Quality control must be combined with productivity and downtime control to allow the control of maintenance costs.

The development of a maintenance quality control program may be approached in several ways but the following elements should be includeed: (108)

1. Examine Purchase Practices - If an operation buys top quality supplies, the repairs made to facilities tend to be good so, improvement in quality should parallel improved purchasing practices.

The same applies to tools supplied to tradesmen.

2. Analyze Work Performance - This is another method of improving the quality of maintenance work. Follow-up by supervisors should be encouraged. The quality of work can be controlled by close supervision of work habits but good housekeeping and workmanship should also be emphasized.
3. Motivate Tradesmen - Pride and motivation go hand-in-hand; when a tradesman is proud of his work, he is inclined to produce better quality work.
4. Train (Re-train) Personnel - Good training undoubtedly improves the quality of maintenance work. In fact, upgrading workers' skills is a prerequisite to getting quality performance from them.
5. Review PM Practices - Optimize inspection frequencies. Ensure that inspections and testing procedures are comprehensive. Make PM checklists as simple as possible to follow. Encourage supervisors to accompany tradesmen occasionally to make sure that work is properly done.
6. Establish Good Planning and Scheduling Procedures - High-quality maintenance cannot be expected if jobs are not studied in advance, problems are not anticipated, and the correct tools and materials are not made available. Any maintenance operation supported by good planning and scheduling can provide quality service to the company.

Implementing a maintenance quality control program requires preparation. If maintenance develops quality standards, improves technical know-how, and trains its workforce, it can achieve whatever degree of quality control it desires.

6.2.4 Cost Control

Cost control is not really the strong side of maintenance. (84) In fact, as mentioned earlier, the only way maintenance can control its costs is by exercising control over those factors that affect them: productivity (labour and materials), downtime, and quality. Maintenance does have control over time, materials and methods used, but not the cost of these.

However, the cost of maintenance continues to rise and some degree of control must be applied if operations are to reduce this cost. Many managers have attempted to reduce maintenance costs by arbitrarily reducing their workforce, but this has only resulted in a reduced maintenance effort which leads to the development of a crisis situation. How then can maintenance costs be controlled and reduced?

In attempting to provide an answer to this question, Tomlingson identified a number of facts that can be of help in this area: (104)

1. Total maintenance costs are controlled by the cost of material consumed, not by the cost of labour.
2. Maintenance labour unit cost is relatively stable, variations are primarily due to overtime.
3. Labour costs are incurred primarily as a result of the need to install materials.
4. Maintenance material costs are determined by the number of units to be maintained and the work load on these units.
5. The only significant control that maintenance has over costs is the efficiency with which it utilizes its material resources.

Apart from the above facts, maintenance can exercise some degree of control over annual maintenance costs by establishing a well-prepared budget, based on tight but realistic cost levels. Attainment of or staying within such levels will only be possible by efficient working. The requirement that maintenance personnel work with such a device will force them to plan and control those activities that directly affect cost.

Moreover, with a well-prepared budget as a guide, there are a number of cost control techniques available to maintenance managers. The most common of these is "marginal analysis" which makes it possible to base decisions on quantitative insights. For example, very often a manager must decide whether to work personnel overtime to repair a piece of equipment. If the decision is made not to repair, a shutdown may result if the unit fails on the backshift. Therefore, the likelihood and consequences of a shutdown must be weighed against the extra cost of making the repairs on overtime. Marginal analysis which involves considerations of operating level and the risk of unit failures can guide such a decision.

Continual monitoring (weekly, monthly) of maintenance costs is yet another strategy available to maintenance managers. Monthly reports showing the cost of labour and material charged against units of equipment and major jobs is one method used by a number of operations. These reports should include year-to-date cost summaries, manhours spent on regular and overtime work, and budget variances. In addition, long-term monitoring of indicators, such as labour/material ratio, or maintenance cost per unit of production, can provide maintenance with a means of detecting "high cost" areas and trends and aid the implementation of suitable corrective actions.

6.3 Performance Measurement

An essential part of any information system is performance measurement. Whereas "control" reveals what is happening, "performance measurement" shows how well or how poorly it is being done. Performance measurement relates to the expression of results in figures which evaluate a maintenance activity in relation to a target or goal. Control is an indicative tool which provides maintenance with a short-term view. On the other hand, measurement is an assessment tool which is effective on a more long-term basis. However, the relevant techniques are complementary and serve the same purpose: to provide a guidance in fulfilling the maintenance objectives within the overall operation.

There are many indicators of maintenance performance - labour use, costs, backlog, etc. (104) Each measures a specific element and the combination of such measures provides maintenance with an overview of its performance. A wide variety of data can be generated to provide an accurate picture of maintenance performance but the maintenance manager must carefully decide on, and collect the information most suitable to his operation.

Some companies use work sampling in measuring maintenance effort. (109) (see Chapter 8) However, this technique offers no real measure of the actual performance, only indications of how things are going. (109) The techniques discussed in this section are based on the expression of measurements in useful figures.

There are, in general, two ways in which the performance of maintenance can be measured in practice: (84, 49)

1. Measure of Efficiencies - essentially this is a measure of output achieved (monetary savings, etc.) expressed as a percentage of the input to the maintenance function (resources consumed). Although this measure is deemed very fashionable, in practice, it is often very difficult to obtain measures of maintenance outputs and inputs which are suitable for constructing a meaningful efficiency index.
2. Measure of Effectiveness - this is, in effect, a measure of actual performance against planned performance. A necessary pre-requisite of employing this measure is the definition of a goal or objective to be achieved. The development of such measures of performance has received considerable attention.

It is up to maintenance management to decide which of the two measures or which compromise is best for its operation. However, even more important is the recognition that a suitable measure of performance must be developed in order to assess the performance of the maintenance function.

6.3.1 Measures of Performance: Desirable Properties

Having decided that some measure of maintenance performance will be beneficial, it is necessary to decide the properties that such a measure should possess. Some of these are: (49)

1. The measure should be relatively easy to calculate and use; complexity takes away any potential benefits that the measure may afford.
2. Overall maintenance performance should not be difficult to interpret from the information provided.
3. The measure should accurately reflect management's concepts of what constitutes maintenance performance, especially with respect to the organizational objectives.
4. The measure should indicate when something has gone wrong and what remedial action is necessary.
5. Measures should reflect all the relevant consequences which affect maintenance performance.

Measures of performance seldom, if ever, satisfy all of these above requirements, but some of these requirements are more important than others. All measures of performance should satisfy requirement (4) and should endeavour to satisfy requirement (1).

6.3.2 Existing Measures of Performance

This section discusses three methods, now in use, to measure the performance of the maintenance function. These methods demonstrate the different approaches used and the reader may decide which method is best suited to his organization. The common factor in all is the use of indices (ratios); the advantages and/or shortfalls depend on the use that is made of them.

Corder's Index of Maintenance Efficiency

Corder (49) claims that the following index represents the relative merits, on a year-to-year basis, of the maintenance function within an organization:

$$E = \frac{K}{xC + yL + zW}$$

where

K = A constant such that the index equals 100 in the base year.

C = Total maintenance cost expressed as a percentage of replacement value of the plant and equipment.

L = Lost time due to maintenance causes expressed as a percentage of the scheduled production hours.

W = Waste of materials due to maintenance causes expressed as a percentage of the total output at the appropriate stage of the operation.

x = Total cost of maintenance in the base year.

y = Total cost of lost time due to maintenance causes in the base year.

z = Total cost of waste produced due to maintenance causes in the base year.

This index incorporates some desirable properties, the two main ones being that it is simple to calculate and indicates (by a decreasing year-to-year index value) when something has gone wrong. However, only an experienced manager can decide, from this index, what corrective action is necessary.

Priel's Indices of Maintenance Effectiveness

Priel's (49, 84) approach to the measuring of maintenance differs from that of Corder in that he proposes a large number of indices (see Table 6.2) rather than one index. This approach allows the user to take some account of relevant consequence variables.

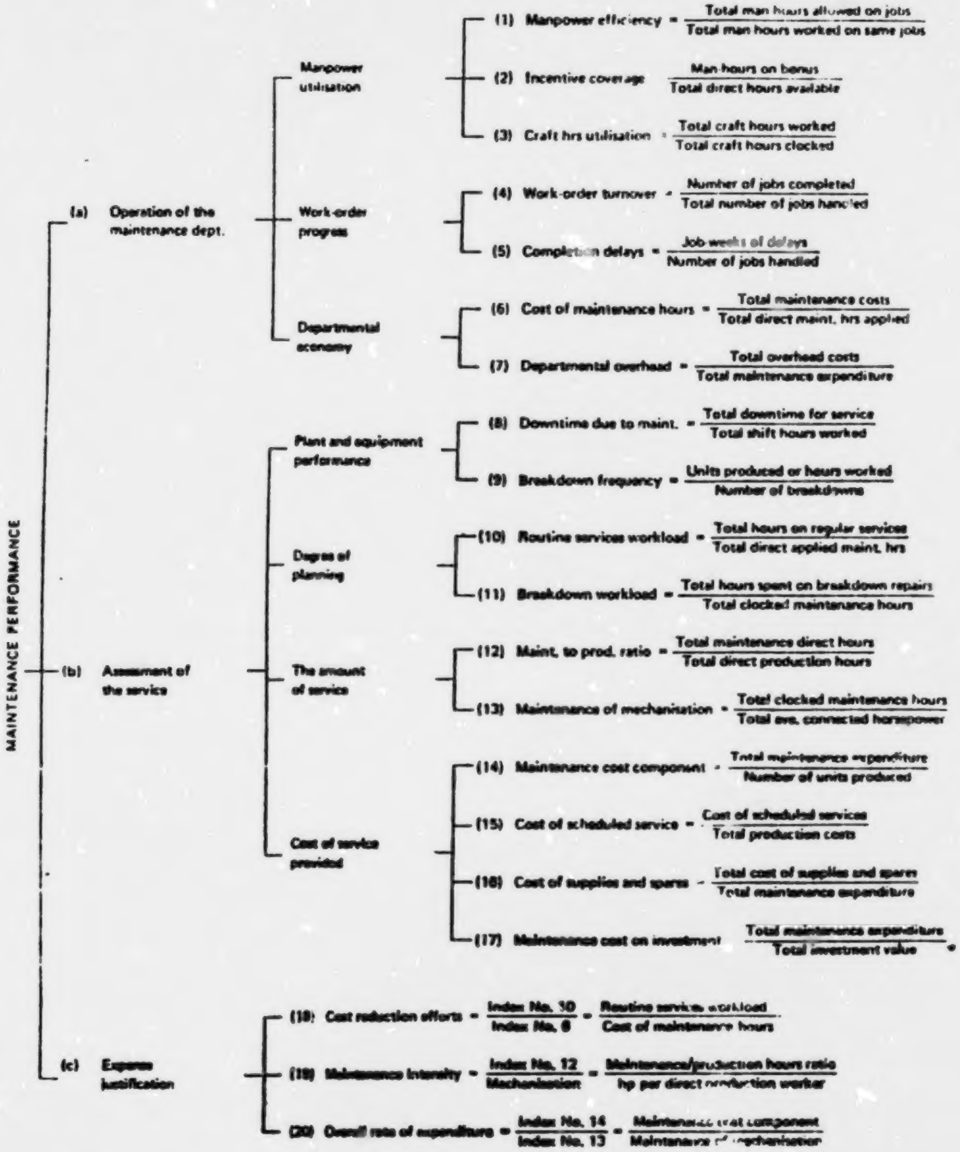
Since a large number of indices do involve a large numer of consequence variables, it is more likely that this method will better identify the cause of poor maintenance performance.

Luck's Composite-service Method

This measure of maintenance performance employs a combination of the methods used by Priel and Corder. It requires sixteen indices, four in each of the following categories:

- planning
- work load
- cost
- productivity.

Table 6.2 Priel's Maintenance Performance Ratios (49, 84)



MAINTENANCE PERFORMANCE

- (a) Operation of the maintenance dept.
  - Manpower utilisation
    - (1) Manpower efficiency $= \frac{\text{Total man hours allowed on jobs}}{\text{Total man hours worked on same jobs}}$
    - (2) Incentive coverage $\frac{\text{Man-hours on bonus}}{\text{Total direct hours available}}$
    - (3) Craft hrs utilisation $= \frac{\text{Total craft hours worked}}{\text{Total craft hours clocked}}$
  - Work-order progress
    - (4) Work-order turnover $= \frac{\text{Number of jobs completed}}{\text{Total number of jobs handled}}$
    - (5) Completion delays $= \frac{\text{Job-weeks of delays}}{\text{Number of jobs handled}}$
  - Departmental economy
    - (6) Cost of maintenance hours $= \frac{\text{Total maintenance costs}}{\text{Total direct maint. hrs applied}}$
    - (7) Departmental overhead $= \frac{\text{Total overhead costs}}{\text{Total maintenance expenditure}}$
- (b) Assessment of the service
  - Plant and equipment performance
    - (8) Downtime due to maint. $= \frac{\text{Total downtime for service}}{\text{Total shift hours worked}}$
    - (9) Breakdown frequency $= \frac{\text{Units produced or hours worked}}{\text{Number of breakdowns}}$
  - Degree of planning
    - (10) Routine services workload $= \frac{\text{Total hours on regular services}}{\text{Total direct applied maint. hrs}}$
    - (11) Breakdown workload $= \frac{\text{Total hours spent on breakdown repairs}}{\text{Total clocked maintenance hours}}$
  - The amount of service
    - (12) Maint. to prod. ratio $= \frac{\text{Total maintenance direct hours}}{\text{Total direct production hours}}$
    - (13) Maintenance of mechanisation $= \frac{\text{Total clocked maintenance hours}}{\text{Total ave. connected horsepower}}$
  - Cost of service provided
    - (14) Maintenance cost component $= \frac{\text{Total maintenance expenditure}}{\text{Number of units produced}}$
    - (15) Cost of scheduled service $= \frac{\text{Cost of scheduled services}}{\text{Total production costs}}$
    - (16) Cost of supplies and spares $= \frac{\text{Total cost of supplies and spares}}{\text{Total maintenance expenditure}}$
    - (17) Maintenance cost on investment $\frac{\text{Total maintenance expenditure}}{\text{Total investment value}}$
- (c) Expense justification
  - (18) Cost reduction efforts $= \frac{\text{Index No. 10}}{\text{Index No. 6}} = \frac{\text{Routine services workload}}{\text{Cost of maintenance hours}}$
  - (19) Maintenance intensity $= \frac{\text{Index No. 12}}{\text{Mechanisation}} = \frac{\text{Maintenance/production hours ratio}}{\text{hp per direct production worker}}$
  - (20) Overall rate of expenditure $= \frac{\text{Index No. 14}}{\text{Index No. 13}} = \frac{\text{Maintenance cost component}}{\text{Maintenance of mechanisation}}$

Luck (23, 49) does not define the indices in any detail but he stresses that the choice of indices should be decided by each organization. It is also necessary for the management to establish objectives or goals in each of the above categories. Actual index values are determined from a survey/analysis of maintenance.

The following are the steps for Luck's composite-service method:

1. Select four indices in each of the above four categories, each index being representative of the particular category. For example, in the work planning category, suitable indices are:

   - labour effectiveness
   - emergency work
   - work planned
   - overtime

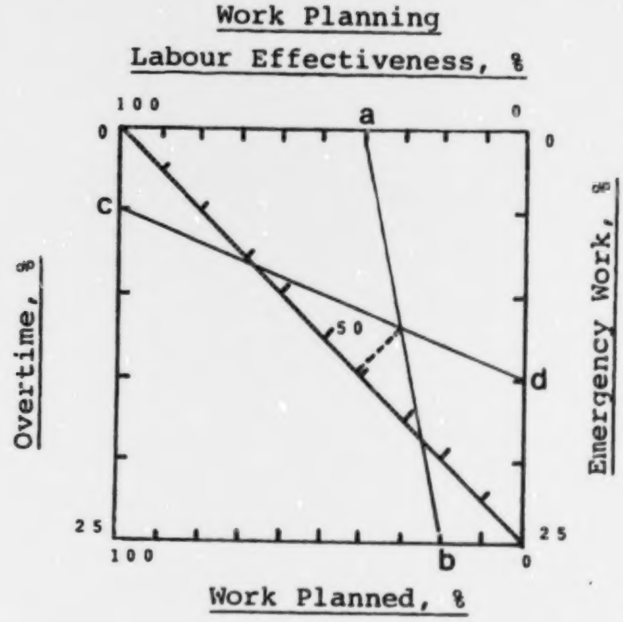
2. Determine the value of each index from a survey/analysis of the maintenance operations.

3. Plot each index value on the appropriate chart axis, as illustrated in the work planning chart of Figure 6.3, and connect the values on opposite sides by straight lines.

4. Draw a dotted line from the intersection point of the two lines, perpendicular to the diagonal point-value line. The point value for service capability is read where the dotted line crosses the point-value line.

5. Repeat the above steps in each of the other three categories.

6. Using the point values obtained and the composite-service chart shown in Figure 6.3, repeat steps 3 and 4 to determine the composite service point value. Target values should also be used for comparison.


Work Planning
Labour Effectiveness, %
100
a
0
0
c
0
Overtime, %
50
d
Emergency Work, %
25
100
b
0
25
Work Planned, %

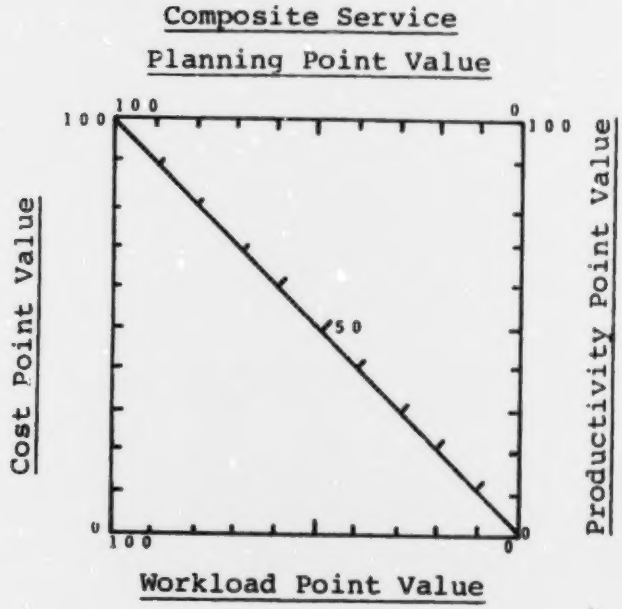

Composite Service
Planning Point Value
100
0
100
100
Cost Point Value
50
Productivity Point Value
0
100
0
0
Workload Point Value

Fig. 6.3 Luck's graphical procedure (23, 49)

Application of this technique involves drawing a total of five graphs and, because this can be very time consuming, the approach is not necessarily suitable for manual application. (For full details see references 23 and 49) (23).

It must be emphasized, of course, that indices, such as those suggested by Corder, Priel, Luck are essentially descriptive rather than prescriptive. That is, such indices say nothing about the future performance of maintenance as a result of actions taken on the basis of the index values. Therefore, before an index is used as a basis for decision-making, an analysis of possible consequences should be made to determine which decisions are compatible with the operation's overall objectives.

6.4 Conclusion

The information system is the binder of the maintenance management program, holding the other elements together by providing the administration with feedback data which allows it to monitor, control and upgrade all aspects of the program. Without reliable information, control of the maintenance function is virtually impossible.

The description in this chapter applies equally well to a manual program or a computerized one. However, as the size and complexity of the maintenance operation increases, manual information collection and control become difficult; some form of automation becomes necessary.

Computerization, which is the subject of a subsequent chapter, is becoming an integral part of the maintenance information system and in mining situations it is essential. However, unless a sound foundation, in the form of a manual information system, is in place, computer application for improved maintenance control will yield minimum benefit.

Chapter 7

COMPUTER APPLICATION TO MAINTENANCE MANAGEMENT

In the mining industry, maintenance is probably the single largest controllable expense. (26) However, in spite of this, computers have been used infrequently for maintenance control and when they have been used, it has been with limited success.

Some of the reasons why computers have not been used more successfully for maintenance control, in mining operations, are inherent in the attitude of mine management. The maintenance function is not usually part of the main stream of the organization. Top management is often unaware of the problems in the maintenance department and tends to regard it as an unknown, but necessary and costly evil. In most cases, the computer applications attempted have been imposed on maintenance from another area, notably the data-processing area. (26) While data-processing help is essential to computer application, computerized maintenance systems should be initiated from within the department rather than from outside. In this way, maintenance personnel are involved in the development and implementation of the system and feel more responsible for its success and failure.

However, the primary problem with computer application to maintenance control has been the method selected in the past. The method most often chosen has been the "batch method." The maintenance department prepared the input and the information was then sent to the data-processing section for processing. The results were usually returned the next day or even the next week. Such a system did not help the maintenance department handle the day-to-day problems arising from maintenance activities and moreover, was too slow and unresponsive to the needs of the maintenance department.

Within the last ten years, computers have become a significant force in modern maintenance management. (81) The advent of low-cost computer technology (hardware and software) which includes such recent developments as: (26)

- on-line visual display terminals,
- display, fill-in-the-blank systems,
- modularized data base, and
- pre-prepared software packages.

The features have made computer solutions available to even the smallest of companies. With the mining industry utilizing highly diverse and sophisticated equipment, the problems of maintenance management are very complex, so such solutions are most desirable.

To undervalue the role of computer technology and its application in the maintenance area of the mining industry would be a serious oversight, especially since computerized maintenance management forms a strategic element of efficient mining practice.

7.1 Manual versus Computer-based System

There is little difference in the data provided by a good manual system and that provided by a computer-based system for maintenance control. In fact, a manual maintenance system is a necessary predecessor to a computer-based system. The former provides the foundation on which the latter can be built. In the absence of a sound manual system, computerization of the maintenance function is virtually impossible.

The real difference between the two systems is in the areas of data storage, data retrieval, volume of data that can be handled, and the speed of feedback. With these features scheduling of maintenance work is much faster, and virtually automatic in a computer-based system, particularly in application to PM work. Also, information accumulation, storage and retrieval are much easier in a computer-based system so that performance, backlog and other reports can be produced more or less automatically.

Actually, a computerized maintenance program is an extension of the basic maintenance control program. (69) The supporting and essential elements discussed in Chapters 2 to 6 are the vital foundation of any computerized maintenance system; the computer simply improves maintenance control. It is only a device that collects information, audits, organizes and stores data to furnish the reports necessary for maintenance decision-making. The effectiveness of a system depends entirely on the user's ability to make use of the information generated.

Computers do not and cannot run the maintenance operation; all decisions concerning maintenance actions must be made by qualified supervisory personnel. However, the computer does eliminate a lot of paperwork the supervisor would otherwise have to do and also reduces the amount of the time he would spend on clerical activities.

In summary, a program should always serve the user, not the user serve the program.

7.2 Data-base Files and Input

Files form the backbone or data base of the computerized maintenance program and are used to store large amounts of historical and current maintenance information. The program must be as flexible as possible and provisions must be made for the system to accept as many pieces of information as necessary. However, the amount of data actually set up in the data base should always be optimal: no more than is required for achieving maximum control of the maintenance operation.

The core of any maintenance program consists of two basic files: (5)

- Preventive Maintenance (PM) file
- Work Order (WO) file.

These two master files are interconnecting and are made up of other files that provide logical data to enable the overall program to function efficiently as follows:

1. Preventive Maintenance (PM) Master File (5, 21)
    - equipment/component file
    - material/spare parts file

  - personnel file
  - PM-procedure and frequency file
  - PM-history file
2. Work Order (WO) Master file (5, 21)
  - work order history file

7.2.1 PM Master File

This is considered a static file and stored information rarely requires updating unless there is a change in any initial input. Stored information includes: (5, 21, 52, 55)

a) Equipment/Component file

- equipment specifications, extracted from manufacturer's handbook,
- equipment identification such as model, serial number, etc.
- major components identification and description
- data of purchase, supplier's name, cost centre number, location.

Easy access to this file is of great value to front-line supervisors and planners in support of planning and scheduling maintenance actions. Equipment is usually cross-referenced by various reference items. (52)

b) Material/Spare Parts File

A complete bill of material for each piece of equipment is made available on this file. For each part, or in some cases for critical parts, the list shows: (5, 52, 55)

- inventory number (stock item)
- manufacturer's part number
- stores location and quantity
- brief part description
- list of equipment using similar parts.

Parts can therefore be identified quickly through an on-line inquiry rather than by searching through the warehouse trying to match up parts.

c) Personnel File (81)

This is an optional file but, when included in a program, inputs include personnel's:

- name and ID number
- experience and skill
- training received
- length of service.

Information stores is of value to manpower planning and training programs.

d) PM-Procedure and Frequency File (21)

- detailed checklist for each PM task
- manpower requirements, estimated hours
- PM established frequency in operating hours or calendar days
- special instructions, eg. test, calibration tolerance, etc.

e) PM-History File

In many programs this is combined with the WO history file. As a separate file, it stores information on completed PM orders. When a PM action is complete, all relevant information is transferred to this file and stored for future use. In a mobile maintenance program, records maintained include equipment operating statistics, component changeout histories, fuel consumption and age of tires. In most programs entries into this file are automatic; it is therefore always up-to-date.

The basic function of the PM master file is to generate automatically PM orders (service/inspection sheets) that are used to implement and schedule periodic maintenance work. The orders are numbered by the computer and usually grouped by assigned discipline or by similar equipment.

When work is planned for a given period - the coming week, for example, the program scans the PM master file and identifies each PM task whose next due date falls during the period, and for which an order has not yet been issued. The program then issues these orders in accordance with the lead time built into the system.

As each PM order is completed and closed out, the program calculates the next schedule due date, based on the completion date and the specified frequency, and logs in the next due date in the master file. The same program increases the record of the number of PM-order executions by one, and recalculates a new average of labour hours used by each trade in performing the work. In addition, completion information is added to the PM-history file.

7.2.2 Work Order Master File

While the PM file, along with equipment, personnel and spare parts data, can be considered as static, the WO file is the active or dynamic ingredient of the computerized maintenance program. It provides the planned WO schedules of backlog work, to be completed during a specified period, for example, one week.

As mentioned earlier, this file is interconnected with the PM-master file and therefore, when used in conjunction with the data provided in that file (equipment, spare parts, personnel), is able to highlight unavailability of labour/material, thus allowing schedules to be reassessed.

The WO master file is more dynamic than most of the other files because it contains a record for each active work order that has been issued but is not yet completed or cancelled. This file is therefore continually upgraded as WO's are inserted, modified or deleted.

Data input into this file varies with the type of program in place. Most companies seem to retain the conventional maintenance paperwork for work orders and material requisition and therefore manual entries of all the information on these two documents become necessary. In sophisticated programs, WO's are automatically generated and only modification/completion WO-inputs are necessary.

In either case, the essential input information for closing the WO includes:

- WO number
- Worker ID number
- Actual manhours/costs
- Actual materials used/costs
- Completion date
- Brief descriptions of work done and defects identified.

When a completed WO is deleted, it is posted to the WO History file where information concerning equipment, labour, materials and costs is retained for future use.

a) WO History File

This is an important extension of the WO master file. It provides information for improved planning and forecasting to assist management in decisions concerning future equipment/component replacement, modification and selection. Material consumption can be tracked allowing for better stores control of spares and material inventory.

Equipment defects can be continually examined and monitored so that reliability and efficiency can be improved.

If actual maintenance costs are recorded, by charging labour and material costs to the specific WO, then variations in performance versus budget cost can be displayed as a report, providing management with due warning of budget deficits.

7.2.3 File Structure

A computerized maintenance program is a dynamic system and as such, continually requires changes. The files comprising the data base must be designed in such a way that the overall structure is modular. (5, 52, 55) This allows a high degree of flexibility in the use of the program and facilitates upgrading and expansion as the maintenance function matures. Modularization is advantageous for another reason. As maintenance personnel become experienced with the system, many suggestions are made for improvements. These improvements can easily be made without interfering with the remainder of the system.

Usually, the data-base files are sub-divided into two sections: "mandatory" and "optimal". A skeleton system is initially installed by supplying data only for the mandatory section of each file. Then, as the maintenance function matures and increased sophistication is desired, the optimal information is added to expand the system to its full capabilities.

The recurring problem in combining computer technology with the mining industry is the difficulty in bridging the gap between engineer and system analyst. (5) To produce a practical, computerized maintenance system, it is essential to have the full co-operation and enthusiasm of both parties. At all stages of systems specification and development, the engineer should be allowed both flexibility and access so that the program is moulded to the operation's requirements. A comprehensive system requires input from stores, personnel and accounting departments as well as maintenance and production. Many of the software packages currently available on the market are far too general to be of immediate use to the maintenance manager.

In self-developed programs, it must be kept in mind that the objectives of the system are to reduce the amount of paperwork, to develop a system that is simple to use and can be understood by all levels within the maintenance department, and to make pertinent information readily available when it is needed to make decisions. (52)

7.3 Characteristics of a Computerized Maintenance Management Program (CMMP)

The characteristics inherent in a CMMP are directly related to the subroutines included in the program. Not all the subroutines described below are necessarily required by a given operation; a decision as to desirability and degree of sophistication must be made for each program. Ideally, maintenance management would indicate the type of information needed for decision making and the different subroutines would be written around those needs. Subroutines should always be applicable to the particular program.

A computerized maintenance management program for mining application should have the following characteristics: (5, 21, 46, 52, 55)

Generally:

- It should be able to deal with every type of equipment/plant in the operation, ie. both stationary and mobile maintenance.
- It should handle both corrective and preventive maintenance.

Specific requirements or feature characteristics include the following:-

1. On-line Features
   - Input, editing and corrections should all be done on-line and error flagging should be immediate.
   - Inquiry should be on-line and be accessible through a master menu, by planners, foremen and occasionally tradesmen.
   - A "help" menu should be available to facilitate both input and inquiry.
   - Updates should be performed centrally (eg. planning office) and should require a password as a security measure.

2. Physical Features
   - Terminals should be located directly in the maintenance department and should be equipped with CRT screens with attached printers.
   - Program should be interactive, self-prompting and have simplified operating techniques so that employees with very little computer training can easily have access to all information.

3. Job Planning
   - It should provide data for planners to determine the need and availability of parts, tools, drawings, etc., and keep track of work order

status.

- It should allow planners to review backlog according to various selection criteria, such as WO number, priority, equipment number or date requested. Other information useful to planning and selcting jobs, such as:

    - previously planned jobs
    - completed work orders
    - history on equipment
    - stores inventory
    - trades availability

  should be easily available on request.
- It should sort and display WO's by priorities.
- It should provide labour and material estimates.
- It should provide data for estimating the duration of different jobs, using time-slot averages.
- It should provide job standards, detailing the work to be done for repetitive jobs.

4. Scheduling
    - It should provide schedulers with various categories of useful information, such as WO's to be scheduled.
    - It should summarize labour requirements for all areas and compare them with expected availability.
    - It should provide a daily work schedule based on the weekly schedule.
    - It should be able to schedule multiple priorities of work.

5. Preventive Maintenance
    - It should issue PM work orders automatically on a pre-specified basis.
    - It should provide (print-out) PM checklists, with detailed instructions, for tasks to be performed on each piece of equipment or plant. Checklists should specify

frequency and allow for free-form comments to be added.

- It should provide a PM follow-up and/or trigger system for informing personnel when PM work is overdue and/or approaching. It should also provide follow-up for corrective work generated as a result of earlier PM inspection.
- It should automatically calculate the next PM date, based on the completion date and the specified frequency.
- For major pieces of haulage equipment, it should accumulate operating hours and track component changeout history, enabling the analysis of performance, the forecasting of failures, and hence, the determination of the optimal changeout interval.
- It should provide for standards, for major overhauls, to be developed on-line; printing out step-by-step task lists, detailing the scope of work that needs to be done for each job.

6. Stores and Purchasing
   - If not under maintenance jurisdiction, there should be a strong interface between the program and the stores and purchasing systems.
   - Program should provide information on the status of parts, issues and receipts, notification of parts availability, status of "waiting on parts" requests, "parts received" notices, and should calculate order points and quantities based on frequency of use.
   - It should provide an on-line stores catalogue showing spares and substitute parts carried in stock. For a specified part, inquiry should display number on hand, number reserve, on order, order point, supplier's name and substitute part number.

- Parts requirement notices (requisitions) should be automatically forwarded to stores, giving required dates and quantities. For planned jobs, requested parts should be automatically reserved - this is an optional characteristic. Also optional, is an automatic "parts delivery" system. (52)
- When order points are reached, the program should automatically forward the requisition data to the purchasing department.
- To eliminate obsolete spares, program should periodically scan parts records and identify items that have not been used for some period of time.
- For inventory control, program should provide periodic reports on costs, type, and number of parts issued in the period, turnover, and supply in stock.

7. Historical Data and Analysis

- It should provide equipment history showing:

    - date of repair
    - work-order numbers
    - description of repairs
    - codes, priority and cause
    - downtime
    - costs, material and labour
    - accumulative costs

- It should provide the ability to retrieve data in the form most useful for the particular analysis being made.
- It should be able to summarize, categorize and sort data, such as by equipment, component, work orders, and cost centre.
- It should be capable of performing statistical analysis on available failure data - optional.

8. Reporting and Control

- To be effective, the program should supply maintenance management with information from a variety of sources. Information should be provided in a series of reports:

  - weekly performance report by trade
  - weekly backlog summary
  - manpower utilization report
  - maintenance delays, by cause code
  - completed work order report
  - exception report
  - PM backlog report and schedule
  - monthly budget reports by cost centre
  - periodic stores review

- It should provide tables or graphs monthly and yearly trends of such parameters as:

  - maintenance cost/tonne of product
  - maintenance manhours/tonne of product
  - maintenance manhours/equipment operating hour
  - availability
  - production delays resulting from maintenance.

7.4 Software and Hardware

Relatively few mining companies have developed their own computerized maintenance management program. Companies in this category include: Iron Ore Company of Canada, Labrador City, Newfoundland; Kidd Creek Mine Ltd., Timmins, Ontario; Kennecott Minerals Company, Salt Lake City, Utah. (52) Those that have done so, usually took several years, at a very high cost. It was also necessary for them to assemble a team of system analysts and engineers, developing, testing and debugging successive modifications of their program until it worked to their satisfaction. The reader should not under-estimate the magnitude of this task; it is rarely possible to adapt programs that were developed for purposes other than maintenance for use in maintenance management.

Operations wishing to develop their own program must keep in mind that a successful computerized maintenance management program is primarily a "people system", supported by a certain amount of paperwork, assisted by the computer, and not the other way around. (55) Many programs have failed because of over-emphasis on the computer aspects and inadequate provision for the difficulties encountered in the real-life maintenance environment.

A paperless, purely on-line program, where everything is handled on terminals, is not practical in maintenance. (55) In a maintenance environment, information is best entered, edited and displayed on-line, but maintenance personnel, especially front-line staff, should have the information they need on paper to allow them to carry information to the job site, to make notes, and therefore to provide better feedback.

7.4.1 Software Packages

Very often, an operation makes a decision to buy a maintenance software package instead of developing its own; a number of such packages is currently available and a number of consulting firms and companies have developed maintenance software (see Table 7.1) which they claim are suitable for general maintenance management, ie. can be used in any maintenance environment. However, mining companies must be extremely careful when purchasing one of these packages since many are not designed for mining application. As Table 7.1 indicates, there are very few specialized mine maintenance packages.

If one is contemplating buying a maintenance computer software package, one should carefully examine and evaluate the supplier's claims. Many packages are not capable of doing a number of the claims associated with them. Having said this, it should be pointed out that some generalized packages can be adapted, with minor changes, to a mine maintenance situation. However, a purchase should not be

Table 7.1 Suppliers of Maintenance Management Software Packages (26, 52, 55)

1. ABC Management Systems Incorporated
Suite 3, 805 Dupon Street
Bellingham, Washington 98225 Tel. 206-671-5170
Equipment: Any major mainframe
Language: ANSI COBOL

2. Bonner & Moore Incorporated
2727 Allen Parkway
Houston, Texas 77019 Tel. 713-522-6800
Equipment: IBM 8100
Language: ANSI COBOL

3. Decision Science Corporation
Benjamin Fox Pavillion
Jenkintown, Pennsylvania 10946 Tel. 215-887-1970
Equipment: Any
Language: FORTRAN

4. DP Industry Marketing *
Process Industry, IBM Canada Limited
Toronto, Ontario
Equipment: IBM
Language: IBM's DMS II

5. EMA Incorporated, Computer Systems Consultants
270 Metro Square Building
St. Paul, MN 55101 Tel. 612-298-1992
Equipment: HP 3000 Series

6. G.K. Fleming & Associates Limited
1118 Roland Street
Thunder Bay, Ontario P7B 5M4 Tel. 807-298-1992
Equipment: DIGITAL

7. Kennecott Copper Corporation *
P.O. Box 329
Magna, Utah 84044 Tel. 801-534-5480
Equipment: IBM
Language: COBOL (CICS)

Table 7.1 (cont'd) Suppliers of Maintenance Management Software Packages

8. McDonnell Douglas Automation Company
P.O. Box 516, Building 107
St. Louis, MO 63166 Tel. 314-232-8021
Equipment: IBM
Language: ANSI COBOL

9. Met-Chem Canada Incorporated *
1140 Boulevard de Maisonneuve West
Montreal, Quebec H3A 1M9 Tel. 514-288-5211
Equipment: Any

10. Revere Technology & Consulting Company, Incorporated
P.O. Box 848
Scottsboro, AL 35768 Tel. 205-259-1460
Equipment: IBM

* Designed Specifically for Mining Applications

made until a number of factors have been checked out and verified. The following are some of the more important factors: (5, 21, 55)

- program language and functions, including documentation, input and output, and data processing efficiency
- overall suitability to operation's requirements
- flexibility of data base, eg. is it modular?
- reputation of supplier
- success of package in previous applications
- cost.

Although cost and data-processing capability should be primary considerations, one should never select a package purely on these bases. Management's evaluation of a maintenance package must be based on how well it will work in the operation. The initial cost of the package, including purchase and training, will be far less than that of continued operation cost. Therefore, payback depends more on how well the package is accepted by front-line supervisors, how well it works in practice, and most important, by the extent to which it reduces overall maintenance cost.

7.4.2 Computer Hardware

Hardware considerations are just as important as those for software. The following are some of the requirements for computer hardware in maintenance management systems: (46, 55)

1. General purpose mainframes are ideal for maintenance management systems, especially if an existing one, with spare capacity is already in place. They are faster than mini- or micro-computers, can use more terminals, facilitate interfacing with other functions, and are best suited for large operations. Centrally located, mainframes can provide time-sharing or network services, if and when necessary.
2. Mini- or micro-computers can be used, but they are generally low speed, less flexible in operation, and suited to fewer terminals. They are

best suited for small to medium operations. They generally cost less than mainframes.

3. Maintenance management usually requires a large amount of storage; insufficient disk storage can greatly impede and reduce a program's performance. For minis or micros, hard disks rather than floppy disks should be used. The latter are easily damaged and provide less storage than the former.

Generally, the ideal maintenance management should run on any general purpose mainframe, or mini- or micro-computer. It should also be interchangeable between different makes of machines. However, regardless of the hardware selected, the maintenance program, even though interfaced with other functions, should be capable of running independently of other systems in the company. If an existing mainframe cannot provide this facility, then a suitable mini- or micro-computer should be used.

7.5 Conclusion

The foregone discussion is by no means a comprehensive coverage of computer application to maintenance management. It does, however, provide some guidelines and ground rules that should help in the implementation of a computerized maintenance management program.

Computerized maintenance management is essential to the mining industry. For a number of years, the industry has applied computer technology to a number of areas of its operation but application in the area of maintenance has always lagged behind. Since equipment downtime is one of the major reasons for lost production, mining operations must recognize that computer application in the management of their maintenance function can assist in minimizing the level of equipment downtime.

The literature search conducted during the course of this analysis revealed that meaningful information on maintenance management is very rare, and that similar information on computer application is even rarer. Moreover, the majority of the available information is concerned with industries other than mining. The literature also indicates that very few mining companies have developed comprehensive, successful, computerized maintenance programs. Two operations that are in this group are: Kennecott Copper Corporation, Utah, U.S.A.; Bethlehem Mines Corporation, Pennsylvania, U.S.A. Both of these operations have published some information on their programs, available in references 52 and 97 respectively. Visits to a number of Canadian mining operations also revealed that very few have comprehensive computerized maintenance programs and very limited publication of any is available.

With this kind of a situation in the industry, mining operations that are contemplating the introduction of computerized maintenance have two alternatives:

- develop their own, either by trial and error or consultant-assisted
- modify and use available software packages.

For those that choose to follow the first course, it cannot be over-emphasized that the program should be customized to the unique requirements of the company's operations. Specifications should be developed jointly by experienced maintenance personnel and system analysts. For those that follow the second course, software capabilities must be checked out and evaluated using some of the guidelines provided in sections 7.3 and 7.4. Where possible, and in either case, visits to companies with established programs should be arranged. Any available literature, on the experience of other program-developers, should also examined. Both areas can provide valuable information, especially at the initial stage of a program.

There is little doubt that many benefits can be derived from computer application to mine maintenance. Companies with functional programs have reported such benefits as: (15, 52, 97)

- increased equipment availability
- increased productivity of maintenance personnel

- improved control and coordination of maintenance activities
- optimization of maintenance resources
- quick and easy access to a large volume of accurate data
- coordinated support services
- reduced maintenance costs.

However, the problems and disappointments of using computers within maintenance should not be underestimated. The cost of a large system is high and the committments can be discouraging. Coupled with these is a huge allocation, sometimes diversion, of internal resources to both develop the program and change over from the manual systems.

Computers are not an end in themselves. They will never entirely replace people in the maintenance environment, nor should such be attempted. However, applied properly and supplied with the right kind of information, they can provide timely, consistent, accurate information, and valuable assistance for improved maintenance management.

Chapter 8

ANALYTICAL TECHNIQUES IN MAINTENANCE MANAGEMENT

Until fairly recently, maintenance management was expected to deal with complex problems and to make critical decisions without the application of any quantitative assessment of the factors involved. (48) Managers relied very much on subjective judgement - experience in most cases - and rarely sought means of performing in an optimal manner. (48) As a direct result, many programs/policies failed or were cancelled because they proved ineffective and more often than not, very expensive.

In the last few years the situation has changed. The high cost of maintenance - accounting for as much as 55% of the total operating budget in many cases - has forced industrial management to adopt a more quantitative rather than a qualitative approach to the maintenance decisionmaking process. This change is very much evident in such industries as manufacturing, airlines and the military where operations research and industrial engineering techniques have been extensively applied to many areas of maintenance. For example, refinements of reliability statistical techniques now allow personnel to develop mathematical models that assist in optimizing such decisions as: (48, 49, 93, 111)

- spare-part inventory
- replacement time/interval
- inspection frequency
- overhaul repair
- scheduling
- work force requirement.

Sophisticated decision models are justified in these industries because operating conditions are usually stable and parameters such as component/item life and failure patterns are often well established.

In the mining industry, operating conditions and component life vary greatly and are often not predictable, accurately enough, to justify the application of these models with the same level of sophistication. However, simpler models based on the same theories, can be used to analyze failure data and to assist managers in optimizing similar decisions. There is little evidence, in the literature, of operations research and industrial engineering techniques being applied to any appreciable degree in mine maintenance. Many mine maintenance programs now collect and record failure data but it is far from fully utilized and, all too often, is used simply for bookkeeping purposes. (111)

Improvement in mine maintenance management cannot and will not be achieved through continued reliance on subjective judgement. Some form of quantitative or analytical approach must be adopted if mine maintenance is to perform in an optimal manner. An example can be taken from the industries previously mentioned where application of analytical techniques resulted in significant improvement in maintenance performance. If suitably adapted with limitations appreciated, analytical techniques can help to reduce reliance on subjective judgement in mine maintenance decision-making.

This chapter will attempt to clarify the use and limitations of operations research and industrial engineering in the field of mine maintenance. Essentially, it will provide the reader with an insight into the informational content of failure data and show how this can be used to determine optimum maintenance/replacement policies. Specifically, in the area of reliability, emphasis is placed on the graphical techniques of Weibull analysis and Glasser's graphs.

8.1 Industrial Engineering (Work Study) Techniques

Although work study has not yet been applied to maintenance in the mining industry to any degree, it does show promise of providing management with another tool to increase the effectiveness of maintenance and to reduce maintenance costs. Today's highly mechanized mining environment will influence the maintenance techniques of the future and work study will play a major role in moulding them.

Many aspects of maintenance lend themselves to the application of work study. (84) It would be wrong to view work study as being simply measurements to establish job times and to award incentives. It is a discipline that provides a sytematic-analytical approach that can help to effect improvement in many areas of maintenance.

As an analytical tool, work study includes such techniques as work measurement (time study), motion study, work sampling and layout studies. These techniques find wide applications in such areas as tool rooms, stores warehouses, workshops and even the establishing of routines for repetitive jobs. The most helpful part of work study is its potential for analysis. By getting the facts of a problem situation in maintenance and by quantifying its variables, work study becomes a problem-solving tool, invaluable to troubleshooting.

A list of the areas in which work study can be useful to maintenance would include the following: (84, 109)

- standards for repetitive jobs, ie. job times and work specifications
- standardization of equipment, spares, lubrication, etc.
- job planning based on timing of work
- layouts of workshops, tool rooms, warehouses
- paperwork procedures.

Work study techniques can serve as fact finders and at the same time help in solving many of maintenance's day-to-day problems. The two techniques that are commonly applied to maintenance situations are work measurement and work sampling. Some detail on these techniques follows.

8.1.1 Work Measurement Techniques

The work measurement techniques used in maintenance range from simple job timing to data block systems, such as motion time method (MTM). Within these extremes a number of other work measurement techniques, such as estimated time standards, are practiced.

Work measurement is intended to provide a scale for the evaluation of workforce performance in the maintenance environment; it is not a substitute for supervision. If introduced against a background of inadequate training, inadequate planning, ineffective stores or other supporting systems and poor technical information, it can result in ridicule of the managment methods. (109) When introducing work measurement, therefore, a thorough investigation of all other management aspects is essential and care must be taken to introduce a competent and comprehensive plan.

Repetitive maintenance work is usually timed by the normal stop-watch method and, for accurate results, measurements must be repeated over a period of weeks or months to produce average results for the various personnel involved.

For non-repetitive work, a technique known as Work Content Comparison (109) is used. This technique produces a set of time bands and if a job is placed in the correct time band or slot, the mid-point of the band will represent a measure for the job. The technique is based on two principle methods: (109)

- analytical estimating
- comparative estimating.

Analytical estimating is usually reserved for a skilled applicator and involves breaking down a job in terms of standard units combined with non-standard estimated work. This method gives closer control that whole-job estimating (as employed in repetitive work) and also allows examination of methods used and work sequence adopted. In comparative estimating (originated in the U.S.A.) a catalogue of standard (benchmark) times is developed on which time allocations are based. The catalogue is arranged according to skills, type of job and time range. A time range rather than a absolute fixed time, allows for variation in working conditions and other influencing factors.

Maintenance management programs that include work measurement have reduced maintenance cost in many cases. A number of manufacturing and chemical processing plants have reported (69) significant reductions in their maintenance labour costs subsequent to the implementation of a work measurement programs. Other reports (69) have indicated that plants without a work measurement program typically find that their work force is only 35 percent effective. A work measurement program helps the maintenance department to achieve the following: (69, 84, 109)

- higher utilization of manpower
- better maintenance scheduling
- better control of crew sizes
- more efficient manning of jobs
- identify areas in which additional training is necessary
- better material specifications.

The goal of maintenance work measurement is cost reduction while improving the capability of the maintenance service. But work measurement alone is not the answer to these objectives. A reliable management program including features like a work-order system, proper planning and scheduling, and qualified and skilled personnel with adequate supervision is also essential to the effective utilization of labour. However, without work measurement, management will never know where it is in regard to maintenance performance.

8.1.2 Work Sampling Techniques

The maintenance manager has a continuing need for reliable data on manpower utilization and performance of the maintenance function. As mentioned in Chapter 6, it is this type of information that allows him to effectively control or manage his available resources. While regular reports deal with labour use, backlog, etc., they rarely provide information on workforce performance.

Usually, performance information is required periodically, to measure progress, and there is little justification for requiring continuing reports. Work sampling or random sampling, as it is sometimes called, can be used to meet these needs.

The principles of work sampling are well rooted in statistical theory. It is a statistical approach to data collecting based on the laws of probability. It assumes that a sufficiently large sample of observations, made at random intervals, will provide a resaonably accurate picture of what is actually occurring most of the time. (109) The larger the sample, the more reliable the results will be.

The basic categories of observations which must be defined and established beforehand should include the following : (69, 109)

Working - at worksite, but not performing productive work
Idle - at worksite, but not performing productive work
Delays - idle, away from worksite
Traveling - moving between worksite, to and from, with or wihout materials, tools, etc.

Clerical - completing documents, time cards, requisitions, etc.

In addition to the above, the routes that are to be used for observation should be established. They must include areas of high work intensity and those with bottlenecks. Since the actual practice of work sampling is well covered in the literature, the remainder of this section will be limited to its applicability to maintenance. In what ways can work sampling assist maintenance?

Although in certain applications it can provide information on job times, this is not its best application. The areas to which work sampling is well suited are: (104, 109)

- Broad manpower utilization, such as for PM inspections and repair work - measured in manhours
- Distribution and frequency of job elements in maintenance crews
- Establishing frequency of occurrence, ie. idle time, waiting time, productive time

- Manpower costing for use in evaluating maintenance productivity
- Major maintenance project work such as shutdown, construction and modification activities.

In recent years, work sampling has become a well-documented practice and has been adapted to the latest trend in computerization. However, in small- and medium-sized operations, the technique can be manually applied and often does not require the service of outside consultants. It can be carried out by local staff who have undergone adequate training. While the actual procedure is simple, there are a number of steps that must be observed when a study is made. (104)

1. People concerned must be informed about the purpose of the study
2. Workers and their representatives should be consulted beforehand
3. Intended use of results should be defined in advance
4. Precautions should be taken to avoid biased results.

Work sampling of the maintenance workforce determines the percentage of time that the crew is idle, travelling, productive, etc. It is not a time measure of workforce performance - work measurement is a better technique for that purpose - rather, it is a measure of how effectively the workforce is controlled and managed.

For the interested reader, reference (1) provides very good coverage of work sampling techniques.

8.1.3 Critical Path Methods (CPM)

CPM techniques also known as "network scheduling" and "critical path scheduling" have been widely publicized as significant improvements in scheduling certain maintenance operations. It is used primarily for scheduling "turn-arounds" - planned major overhauls. Management of a growing number of companies, eg. Eldorado Nuclear, (106) has turned to the CPM technique, during the past two years, to help solve the problems of planning, scheduling, and controlling large-scale project work. In many cases, CPM enabled operations to reduce their turnaround time by 10 to 20 percent, with no increase in cost. (69)

The conventional bar-chart technique, though widely used in the maintenance environment, has many limitations. It is not methodical and the user can encounter difficulty in choosing the best plan-schedule for even a small project. Moreover, for large-scale project work, the technique is incapable of taking into account all the planning/scheduling alternatives which can be enormous in many cases. CPM is methodical, and it is worthwhile to look briefly at the way it works.

The project is analyzed by being broken down into all the jobs of which it is composed. An arrow diagram is drawn showing the sequence in which jobs are to be done, the way the commencement of one or more depends on the completion of a predecessor, and the extent to which they are performed in parallel. When the closed network of arrows is completed, units of time are assigned to each job, the time being based on the most accurate estimate. The critical path is then the longest path in time through the project. The jobs along this path allow no "slack" time; they cannot be reduced in time except by the application of additional resources. The jobs not in the critical path do have slack or float; more time is available for their completion than is really necessary. Therefore, considerable savings can be realized by reserving resources for critical jobs and taking advantage of the float time on all other jobs.

The CPM and associated techniques are widely covered in the literature. (69, 84, 106, 109) For the interested reader, the following text is recommended:

> WIEST, J.D. AND LEVY, F.K., "A Management Guide to PERT/CPM", Prentice-Hall, Inc., Englewood Cliffs, New Jersey, 1969.

8.2 Operations Research Techniques

Operations research is a discipline concerned with the application of scientific nethods to management problems. One of the main tools of this scientific approach is that of building an evaluative model. The model may be of any kind and any complexity. However, it is usually desirable that its behaviour analogues the real system, sufficiently well, to enable the behaviour of the real system to be predicted.

A particularly powerful type of model, and one which finds the widest application in maintenance, is a mathematical model. (76) This model-type relates the performance of a system to its measurable parameters through mathematical formulae. In theory, such a model can be manipulated to maximize the relevant measures of performance. In practice, maintenance can use such a model to evaluate the consequences of alternative decisions, to enable the determination of an optimal policy in relation to a specific objective.

There are many operations research techniques that might be used in building mathematical models. However, in regard to maintenance, the commonly used techniques include: (76)

- Reliability theory - failure statistics
- Replacement theory
- Stock control theory
- Queuing theory.

The particular technique used in a situation depends on the actual problem involved. For example, in attempting to predict component failures, which must be the ultimate desire of every maintenance engineer, reliability theory must be applied. This theory enables the engineer to use available failure data, through a procedure of statistical analysis, to diagnose the nature of repetitive failures and to prescribe possible solutions. Moreover, a useful procedure in some situations is to use statistical failure data and/or analytical functions to construct costing models to estimate the optimum replacement schedule.

This section concentrates on the applications and limitations of failure statistics in mine maintenance management.

8.2.1 Reliability Theory - Failure Statistics

Many of the problem situations in maintenance involve random or probablistic variables. The modelling of such situations therefore, requires a basic understanding of probability and statistics. Failure statistics is the application of statistical techniques to the description and analysis of the patterns of failure of equipment or its separate components. (59) Over the last few years, such techniques have proved to be very helpful to maintenance managers.

Although failure statistics have been applied with much success in such fields as manufacturing, airlines and the military, it has not been generally accepted in the mining and processing industries. (111) However, it can be of some advantage to the mine maintenance engineer in the diagnosis of failures and the prescription of possible solutions/future avoidances.

This section will attempt to acquaint the reader with some of the basic techniques and applications of failure statistics. Specifically the graphical procedure of the Weibull analysis, the construction of simple costing models, and the application of Glasser's graphs for the determination of optimum component-replacement intervals.

Failure Density and Failure Rate

A knowledge of failure density and failure rate are basic requirements for the definition of equipment (component) reliability. In most practical problems one is concerned with "chance of survival" or reliability rather than "chance of failure". Furthermore, a basic understanding of the different parameters used in failure statistics, is essential to successful application. Hence the following definitions: (20, 48, 49)

$R(t)$ = Cumulative probability function of occurrence of survival - reliability
$F(t)$ = cumulative probability function of occurrence of failure
$F(t) = 1 - R(t)$ by definition

The probability density function of occurrence of failure is then given by (20)

$$f(t) = \frac{d}{dt}\,[F(t)] = -\frac{d}{dt}\,[R(t)]$$

In practice, f(t) represents the failure distribution or failure characteristic of a specific piece of equipment or component. This parameter is not the same for different equipment and may not be the same for identical equipment if they are operating under different conditions, which is a very important consideration for mining application.

The failure rate which is of major practical importance can now be defined as (20)

$$(t) = \frac{f(t)}{R(t)} = -\frac{d}{dt}\,\frac{[R(t)]}{R(t)}$$

The various values or quantities appearing in the above analysis have been represented schematically in Figure 8.1 to illustrate the relationship between them.

In Figure 8.1, the area under f(t) - the failure distribution curve - is always equal to unity.

$$\text{Probability of failure before time } t = F(t) = \int_{-\infty}^{t} f(t)dt$$

$$\text{Probability of failure after time } t = R(t) = \int_{t}^{\infty} f(t)dt$$

Failure Patterns

The rate at which a piece of equipment or a component

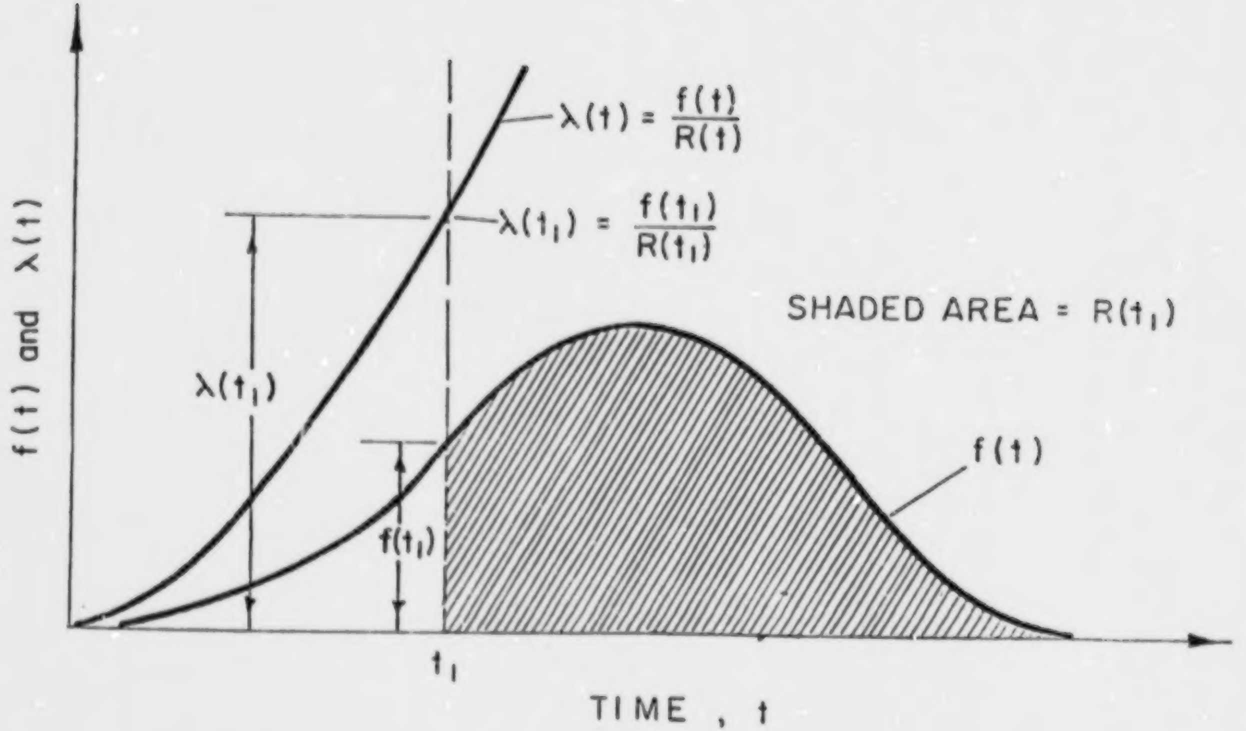

$\lambda(t) = \frac{f(t)}{R(t)}$
$\lambda(t_1) = \frac{f(t_1)}{R(t_1)}$
SHADED AREA = $R(t_1)$
f(t) and λ(t)
$\lambda(t_1)$
$f(t_1)$
f(t)
t_1
TIME , t

Fig. 8.1 Graphical representation of failure rate (20)

fails is a function of the operating life of the given equipment or component. Many failure-causing mechanisms give rise to measured distributions of time-to-failure which approximate quite closely to probability density functions of definite mathematical form, known as probability density functions (pdfs). (59) Such functions provide mathematical models of failure patterns which may be used in performance forecasting calculations.

During the operating life of a given piece of equipment or a non-maintained component, there are three separate operating eras. Each era demonstrates its own peculiar failure-rate pattern. (see Figure 8.2). The three eras and their associated failure-rate patterns are: (20, 49, 50, 59, 111)

- Running-in period (decreasing failure-rate pattern)
- Useful life period (constant failure-rate pattern)
- Wear out period (increasing failure-rate pattern)

a) Running-In Period (20, 59, 111)

With many types of equipment or components the probability of failure is found to be much higher during the period immediately following installation or maintenance than during the subsequent useful life. These failures may occur because of poor workmanship and defective materials during the manufacturing stage. Other reasons may be incorrect installation and/or rough handling during installation. In spite of precautions taken in many cases, running-in failures often occur in practice.

Mine maintenance records, when they do exist, rarely show any segregation of early failures. Furthermore, establishing a "debugging period" or allowing components to "burn-in" prior to installation is not practised extensively. More often, a piece of equipment is taken from the stores, when needed, and installed immediately in order to resume production without further delay.

Mining operations should be aware of early or running-in failures, including the action that manufacturers are

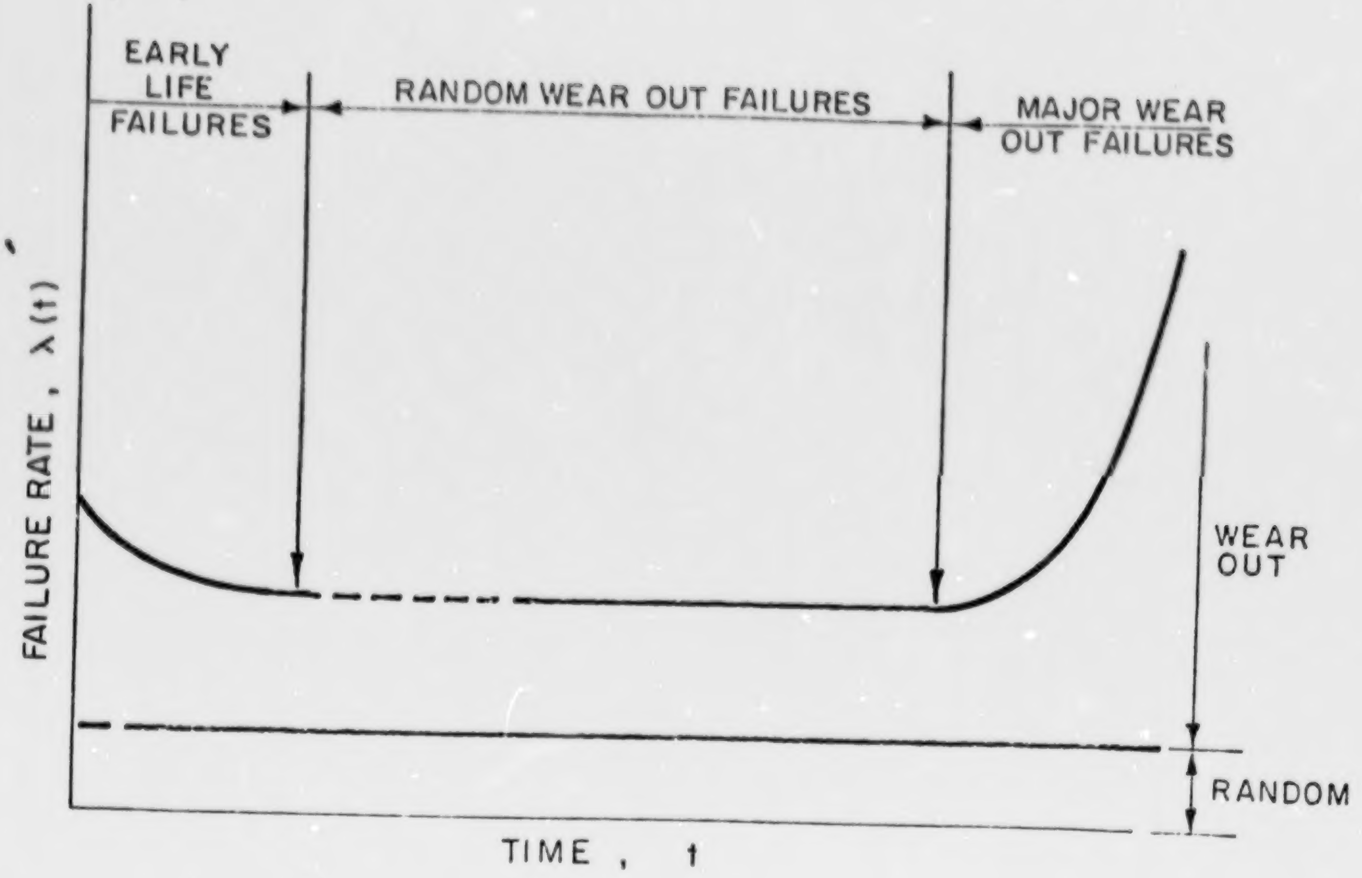


Fig. 8.2 Complete life failure pattern for equipment/component (20)

taking regarding their products. More important, maintenance managers should be aware of the extent to which running-in failures affect failure patterns during useful life.

Early life or running-in failures exhibit a hyper-exponential pdf and a decreasing failure rate. Therefore, in practice, these two failure-behaviour patterns can help to identify manufacture or assembly-related failures.

b) Useful Life Period (20, 59, 111)

A wide range of components and items, under their normal operating conditions and during their normal operating life, do not reach a point of wear-out at some likely time. In short, the probability of failure is constant and independent of running time.

During this period, only chance failures occur and very often the cause is external to the item or component involved.

Chance or purely random failures exhibit a negative exponential pdf and a constant failure rate. In practice, such a failure pattern indicates that the failure mechanism is process- or operation-related, eg. maloperation.

c) Wear Out Period (20, 59, 110)

There is an increasing likelihood of failure as components and/or items grow older and, therefore, the times to failure of a large number of items occur in this operating era. Failure in the wear out period is primarily age-related and due to mechanisms such as abrasion, corrosion and/or fatigue. Very often, it approximates quite closely to the well known "normal pdf".

In the wear out period, failure rate increases rapidly because of both random and wear out failures. It is this increasing failure rate that makes preventive maintenance of items/components suitable during the wear out period.

Unless wear out failures are recorded separately, knowledge of the pattern of wear out will not be available. If the wear out failures are segregated for a given item type, the mean life can be determined; usually in operating hours. However, items will not all fail at exactly the same mean time. Failures will be distributed according to a certain distribution. Experience has shown that in the wear out period this distribution usually approximates the "normal pdf".

Thus, knowledge of the normal pdf enables quantitative predictions to be made about the failures due to wear out.

It must be appreciated that very often causes of failure are not independent of one another and all three forms of failure discussed above may contribute to a particular occurrence. In spite of this, the failure rate curves shown in Figure 8.2 are typical of those obtained in practice for most components and so the distinction drawn above does provide a simple, practical and useful classification of common failures.

The Weibull Distribution

Although the conventional statistical techniques discussed above can be used to describe failure patterns, they are most valuable in isolating their main physical characteristics. Conventional statistical techniques are often too mathematically complex for numerical estimates and/or predictions. It is very convenient, therefore, to have an empirical distribution like the "Weibull" distribution.

The Weibull distribution is a simple empirical expression which can represent any common failure pattern and which is amenable to calculation. (20) It is a particularly useful distribution because of the following reasons: (59)

1. It is a single pdf which can be made to represent any of the three types of pdf's of time-to-failure described in the preceeding section

2. It provides a number of meaningful parameters, such as the probable minimum time to failure

3. There is a simple graphical technique for its practical application.

For these reasons the Weibull distribution is widely used in the practical application of statistical reliability.

The Weibull distribution may be expressed in any of the following forms: (20, 59)

$$f(t) = \frac{\beta}{\eta}\left(\frac{t-t_o}{\eta}\right)^{\beta-1} \exp\left[-\left(\frac{t-t_o}{\eta}\right)^{\beta}\right]$$

$$R(t) = \exp\left[-\left(\frac{t-t_o}{\eta}\right)^{\beta}\right]$$

$$F(t) = 1 - \exp\left[-\left(\frac{t-t_o}{\eta}\right)^{\beta}\right]$$

$$\lambda(t) = \frac{\beta}{\eta}\left(\frac{t-t_o}{\eta}\right)^{\beta-1}$$

Each of the terms in the above expressions has a practical meaning and significance and the following is the practical interpretation of each one: (20, 50, 59)

1. In the Weibull distribution the time factor always occurs as the time interval $(t-t_o)$ where t_o is a locating constant that defines the starting point or origin of the distribution

2. η is a scaling constant known as the Characteristic Life. When $(t-t_o) =$, $R(t) = e^{-1} =$ 0.37, ie. is the interval between t_o and the time at which it can be expected that 63 percent of the items will have failed and 37 percent survived

3. β is a shaping constant which primarily controls the shape of the curve.

   For $\beta < 1$ the distribution takes on the shape associated with early life failures;

For $\beta = 1$ the distribution reduces to the exponential distribution and can thus represent random or chance failures;
For $\beta > 1$ the curve takes on the form associated with wear out of the various types; in particular with $\beta = 3.5$ the distribution approximates the normal distribution.

Thus by appropriate choice of to, η, and β the Weibull equation can be used to represent a wide range of distributions, including both of the practically important random and normal distributions. However, although the Weibull distribution can be used for the vast majority of failure patterns, it is important to note that it is an empirical function and may not be able to represent some particular distributions encountered in practice. (59)

Graphical Procedure for Weibull Analysis (20, 50, 59)

The constants t_o, η, β and in the Weibull distribution for a given set of practical data are best determined graphically using Weibull probability paper. This is illustrated in Figure 8.3. On the Weibull paper the ordinate (Y-axis) is a double natural log scale of $[1-f(t)]^{-1}$ expressed in terms of F(t), while the abscissa (X-axis) is a single natural log scale of the random variable $[t-t_o]$.

Any set of data which follows the Weibull distribution will yield as a linear curve on this paper, as shown by the hypothetical plot in Figure 8.3. The figure also illustrates how the values of β, η, and μ (mean) are determined. The following are the procedures: (20, 59)

1. As shown, a line is drawn through the "estimation point" (at top of figure) and perpendicular to the straight line fit. The point at which this line intersects the special scale at the top of the graph (marked β) gives the value of β.

2. The characteristic life, η, is obtained by extending a horizontal line from the "η estimation", shown on the Y-axis, until it intersects the straight line fit, from this point

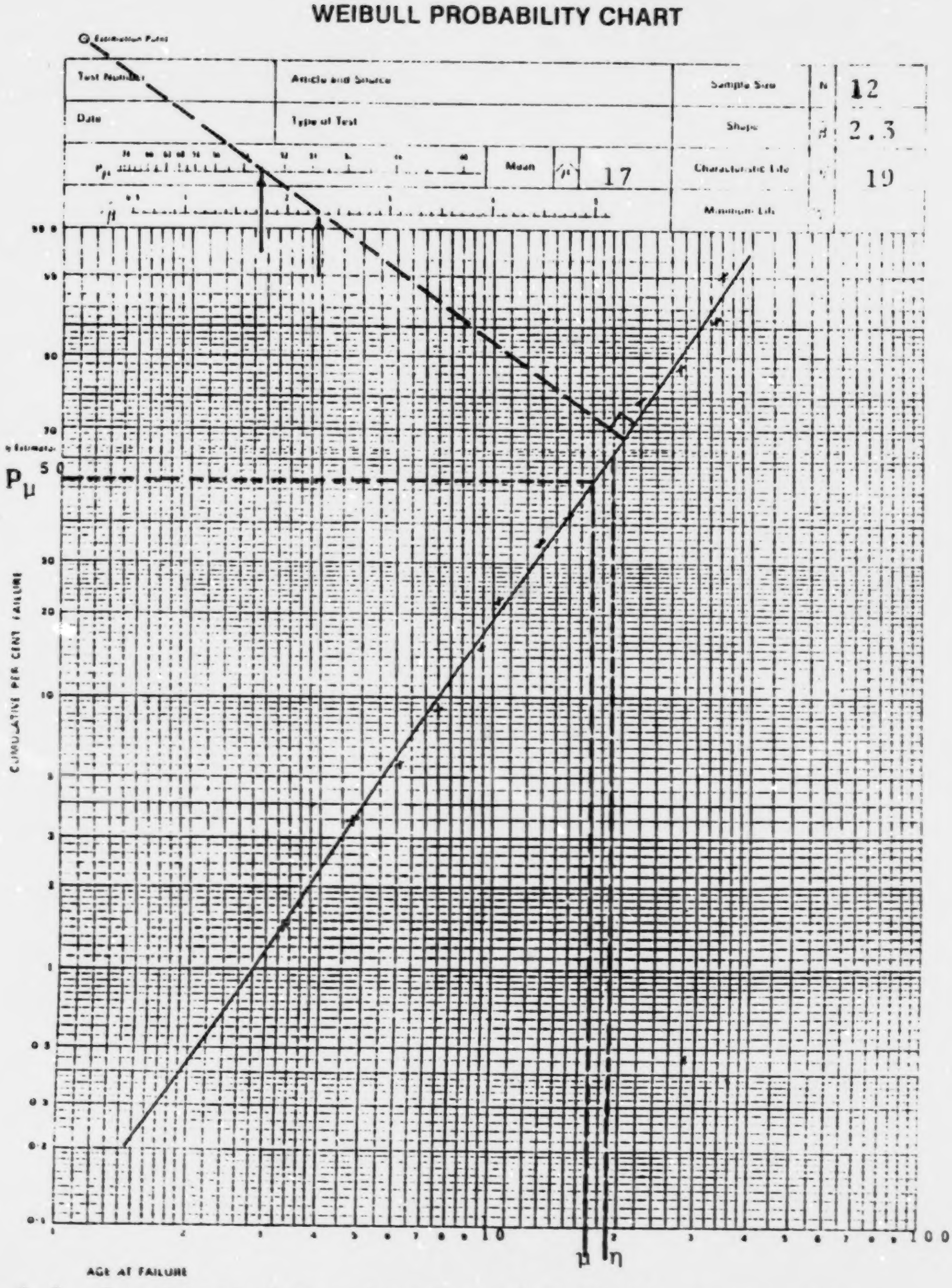


Fig. 8.3 Graphical determination of Weibull parameters (20, 59) (Hypothetical data)

a vertical line is extended downwards to the X-axis. The intersection at this point gives the η value.

3. The μ (mean of the distribution) is obtained by transferring the P_μ value, at the intersection of the perpendicular line with the special scale at the top of the graph, to the appropriate point on the Y-axis, then following the procedure as described in (2) above.

4. Not shown in Figure 83, the standard deviation, σ, is obtained by using the nomograph shown in Figure B1 (Appendix B). The β value is marked on the bottom scale, a vertical line is drawn up from this scale, at the appropriate point, to intersect the top scale. Using the factor obtained:

$$\sigma = \text{Factor X } \eta$$

In practice, arriving at a linear plot may not be as simple as described above. Raw failure data are usually expressed in terms of the variable t rather than $[t-t_o]$. Plotted in terms of t, the curve may be linear in which case $t_o = 0$ and the initial plot can be used for assessment purposes. However, the curve can take on one of the forms illustrated in Figure 8.4. This could mean that the data cannot be represented by the Weibull distribution, or that $t_o = 0$.

If t_o is assumed not to be zero, then its value must be estimated. An arbitrary point is selected approximately in the middle of the curve, as shown in Figure 8.4. Two other points both distant d in the Y-direction are selected and referenced subscript 1, 2, and 3 as illustrated. The equation seen below is then used to calculate the value of t_o. (see reference 20 for derivation)

$$t_o = t_2 - \frac{(t_3-t_2)\ (t_2-t_1)}{(t_3-t_2)-(t_2-t_1)}$$

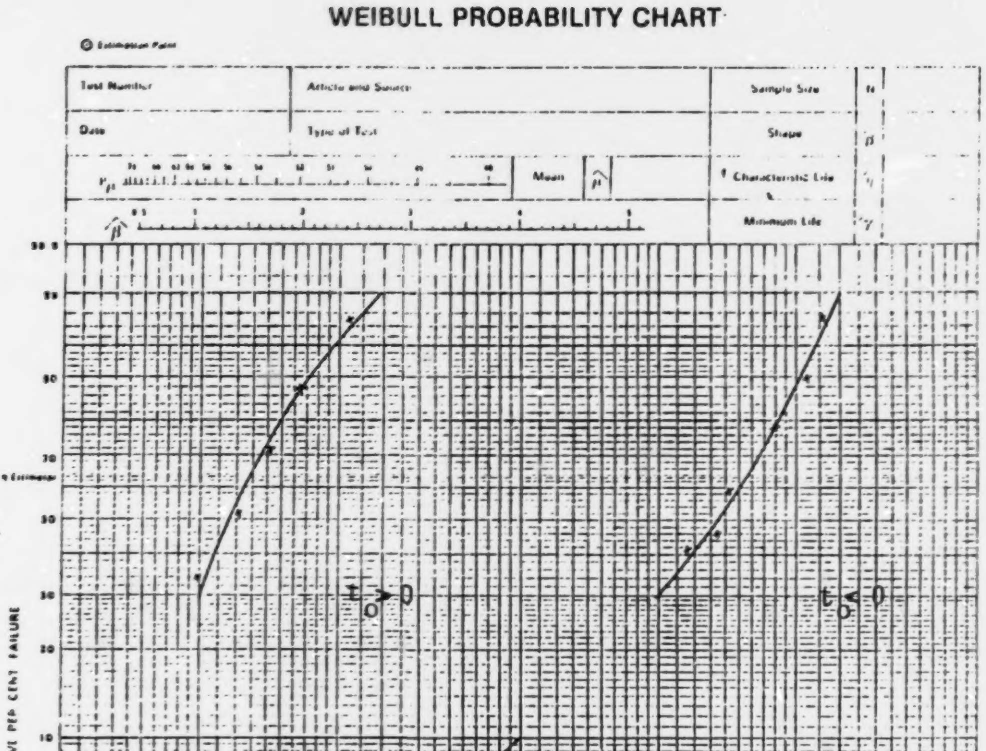


Fig. 8.4 Effect of $t_o \neq 0$ and estimation of t_o value (20)

The value of to can now be calculated and the data replotted using $(t-t_0)$ as the variable. If the data follow the Weibull distribution, the points will lie on a straight line. Some scatter will exist, and the best straight line can be drawn in, either "by eye" or more accurately using the method of least squares. If the data does not follow a straight line then it cannot be represented by the Weibull distribution.

In order to plot failure data on Weibull probability paper, $f(t)$, the cumulative probability function, must be known for each interval. The method used for determining $F(t)$ depends on the nature of the data available.

For ungrouped data and sample size less than 20, $F(t)$ values at the respective intervals are obtained from the "median rank" table shown in Table B1 (Appendix B).

For ungrouped data and sample size greater than 20 then (20)

$$F(t) = \frac{i}{N+1}$$

for the i-th failure, where N is the size of the sample.

In the mining industry, data collected for failure analysis will usually be from equipment that is already being maintained. Thus, some of the data may be censored or suspended (ie. items not having reached the failure point). In this situation a slightly different procedure is required for determining the $F(t)$ value.

For ungrouped data and sample size less than 20, the procedure is as below: (20, 59)

1. Items are ranked in ascending order and classified as failed, f, or suspended (censored), s.
2. For the first failed item the "new increment" is calculated from the formula:

   $$\text{New Increment} = \frac{N+1-(\text{Order number of previous failed item})}{N+1-(\text{Number of previous items})}$$

   where N = total number of items in sample.

3. The adjusted order number of the first failed item is then obtained from the expression:
   Order Number = (new increment + previous order number)
4. This procedure is repeated for all the remaining failed items in the sample, in succession.
5. Having completed the above steps, corresponding F(t) values are calculated from the median rank table.

For grouped data, the procedure is as outlined in Table B2 (see Appendix B).

The foregoing discussion is, by no means, a complete coverage of the Weibull distribution. The subject is covered, in depth, in texts on the statistical analysis of life data. A recommended reference on the subject is:

KING, J.R., "Probability Charts for Decision Making", Industrial Press, New York, 1971.

8.2.2 Application to Maintenance Management

Essentially, the most important application of failure statistics lies in providing information to reliability engineers and/or designers, enabling them to assess system reliabilities and expected lives. However, failure statistics can also be helpful to maintenance managers in two main ways: (20, 48, 49, 59)

- diagnosis of the nature of recurrent failures
- prescription of possible solutions

a) Diagnostic Application

An illustrative example is the best way of explaining this application. Suppose, for example, maintenance management were experiencing problems with recurrent failure of a certain item/component and were unsure of the real cause; analysis of available failure data can help in providing a diagnosis. By analyzing available data (adequate recordkeeping necessary), using the Weibull analysis discussed in section 8.2.1, the parameter will give an indication as to the nature of the failure: (20, 48, 49, 59)

- $\beta = 1$; indicates random failure, constant failure rate
- $\beta < 1$; indicates early failure, decreasing failure rate
- $\beta > 1$; indicates wear-out or aging failure, increasing failure rate.

However, caution must always be exercised in the interpretation of the β parameter. Firstly, although the above represents the common failures encountered in practice, the occurrence of uncommon failure patterns is always possible. Secondly, a recurrent failure may not always exhibit a single failure pattern. It is quite possible that a failure may be due to a combination of causes, in which case, different combinations of the above indications will apply. In practice, a useful technique is to isolate or separate failure data, as much as is practicable, into the operating era in which the failure occurs. (111) In this way the β parameter indications will be somewhat more conclusive.

b) Prescriptive Application

Having identified the nature of a recurrent failure, there are a number of effective actions which can be taken to correct/prevent same. The problem is usually to decide which of these actions is best and there are many factors which influence the decision, and a variety of procedures which can be employed.

Working through a decision tree (a typical one shown in Figure 5.2) is a common procedure. As illustrated in Figure 5.2, the effectiveness of the corrective action is directly related to the failure pattern exhibited and the final decision must incorporate safety contraints and economic factors. A useful procedure in some situations is to use statistics failure data and/or analytical functions to construct costing models, to estimate the most economic replacement schedule. This, however, is applicable only to simple items which exhibit age related failure (β parameter > 1). In other words, for simple items which exhibit age-related failure, preventive replacement schedules can be established and these can be optimized through the construction of costing models, based on statistical failure data.

Before proceeding with an illustrative example of a preventive replacement model, it is important to note that preventive replacement actions require two necessary conditions: (48, 49)

1. The total cost of the replacement (material, labour and downtime) must be greater after failure than before, ie. preventive action must be less expensive than operation to failure
2. The failure rate of the item/component must be increasing, ie. aging or wearing-out must be evident.

Note, however, that these conditions do not apply in the case of complex systems (comprising more than one item/component). Complex systems usually exhibit a constant failure rate (negative exponential failure distribution) and preventive actions in the form of inspections and condition-based monitoring may be very appropriate. (50, 48, 49) Preventive replacement should not be applied in the case of single-component systems which exhibit either a constant or decreasing failure rate. When either is the case, the preventive action does not affect the probability of failure in the next instant, given that the system is good now. Consequently, the application of preventive replacement in either of the two cases is a waste of resources.

Preventive Replacement Models (Single-Component System) (48, 49, 50)

In general, maintenance problems can be categorized as either deterministic or probabilistic.

Deterministic problems are those in which the timing and the outcome of the action are assumed to be known with some certainty. Such problems apply to equipment which is not subject to failure but whose operating cost increases with use. Replacements can be performed to reduce operating cost and after a replacement the trend in operating cost can be assumed to be known. These problems are not typical of mining equipment.

Probabilistic problems are those where timing and outcome of the replacement action depends on chance. In the simplest situation the item is either good or failed. These problems apply to equipment that is subjected to sudden failure and when failure occurs the item/component has to be replaced. Probabilistic problems are very typical of mining equipment and for this reason, the two models illustrated in this section fall into this group.

The models utilize the following assumptions:

- Time to failure is a random variable with known distribution
- The system is either operating or failed
- Maintenance action regenerates the system
- Intervals between maintenance actions are relatively short compared to the operating period of the equipment
- Maintenance cost is generally higher if carried out after an operational failure than before.

The two models illustrated below are representative of:

- a block replacement policy
- an age replacement policy.

a) Model: Block Replacement for Equipment Subject to Breakdown

The objective is to determine the optimal interval between preventive replacements to minimize the total expected replacement cost per unit time.

C_p = cost of a preventive replacement

C_f = cost of a failure replacement

$f(t)$ = probability density function of failure times.

Total expected cost per unit time, for preventive replacement at time t_p), denoted by $C(t_p)$ is

$$C(t_p) = \frac{\text{Total expected cost in integral}}{\text{length of interval}} (0,t_p)$$

Total expected cost in interval $(0,t_p)$

= Cost of preventive replacement + Cost of failure replacement

$= C_p + C_f H(t_p)$

where $H(t_p)$ is the expected number of failures in the interval $(0,t_p)$.

$$H(T) = \sum_{i=0}^{T-1} [1+H(T-i-1)] \int_i^{i+1} f(t)\,dt \quad T > 1 \text{ (Discrete Approach)}$$

Length of interval = t_p

Therefore

$$C(t_p) = \frac{C_p + C_f H(t_p)}{t_p}$$

This model represents the problem of relating replacement interval tp to the total cost $C(t_p)$.

Optimum t_p can be determined by differentiating $C(t_p)$ with respect to t_p and equating to zero. On the other hand, by substituting different values for t_p and producing a graphical plot of $C(t_p)$ against t_p, the optimum replacement interval can be estimated. The latter procedure is recommended for practical application.

b) Model: Age Replacement for Equipment Subject to Breakdown

The objective is to determine the optimal replacement age of the equipment to minimize the total expected replacement cost per unit time. The policy is to perform a preventive replacement at a specified age, t_p, plus failure replacements when necessary.

$C(t_p)$, C_p, C_f, and $f(t)$ are as described in the previous model. However, in this model there are two possible cycles of operation: good and failed.

$$C(t_p) = \frac{\text{Total Expected Replacement Cost Per Cycle}}{\text{Expected Cycle Length}}$$

Total expected replacement cost per cycle
= (Cost of a preventive cycle)(Probability of the cycle)
+ (Cost of a failure cycle)(Probability of the cycle)

$$= C_p R(t_p) + C_f [1-R(t_p)]$$

where $R(t_p)$ is as shown in Figure 8.1.

Expected Cycle Length = (Length of a preventive cycle)
(Probability of cycle)
+ (Length of a failure cycle)
(Probability of cycle)

$$= t_p \text{ X } R(t_p) + M(t_p) \text{ X } [1-R(t_p)]$$

where $M(t_p)$ is the mean time to failure of the failure distribution.

Therefore

$$C(t_p) = \frac{C_p \text{ X } R(t_p) + C_f \text{ X } [1-R(t_p)]}{t_p \text{ X } R(t(_p) + M(t_p) \text{ X } [1-R(t_p)]}$$

This is a model of the problem relating replacement age, t_p to the total expected replacement cost per unit time. Optimization is achieved as in the previous example.

Although both the block and age models generally give the same result, in terms of optimal replacement time, the former is usually more costly. This difference is because the block policy results in nearly-new items being replaced on a preventive basis, whereas, the age policy gets more life on average from an item. However, the age policy will be more costly to implement because records have to be maintained, indicating when an item was last replaced. For expensive/critical items, this extra management cost will almost certainly be worthwhile. (48, 49)

In many practical, mining situations, the above models will be considered too mathematical and far too inconvenient to apply. For such cases, a graphical procedure is available. Glasser's graph shown in Appendix B, Figures B2 and B3 are used to determine the optimal replacement interval and age respectively. The requirements and procedure are also described in Appendix B, Table B3.

8.3 Conclusion

The discussion in this chapter was not intended to provide an exhaustive coverage of analytical tehcniques in maintenance management. It was intended, simply to illustrate to the maintenance engineer or manager some of the current techniques and methods which are available to him, to help in making decisions. Such methods and techniques have evolved to the stage where they have become a maintenance manager's tool. (see references 20, 48, 49, 50, 59)

However, caution must always be exercised in the application of analytical techniques to mine maintenance management. Failures in mining equipment are rarely due to a single cause; more often than not they are due to a variety of reasons. This being the case, it is essential to isolate failure, as much as is practicable, into the operating era in which they occur. This technique helps to better identify particular failure distributions and to determine the effect of one failure pattern on another.

Moreover, the use of reliability (failure) statistics in mine maintenance must be put into the right perspective. Techniques cannot and should not be applied as in the military and/or the manufacturing and other industries. The differences in environmental, human and equipment factors must be given prior consideration.

It must also be emphasized that learning the principles and techniques of statistical failure analysis (operational research generally) is one thing, but collecting and making available a sufficient amount of reliable data for this purpose is quite another. Failure-data collection can be a very expensive exercise and in many situations, notably mining operations, may not be always justified. Failures in a mining environment occur for a variety of reasons and very often can be determined without the aid of failure statistical analysis. However, applied judicially, techniques can be of some assistance to today's mine maintenance managers.

Chapter 9

IMPLEMENTING THE MAINTENANCE PROGRAM

Regardless of how good a maintenance management program may be in its preparation and details, if top management is not sold on the idea and their total commitment is not obtained, the program will fail. Implementing a maintenance management program requires financial assistance from management; the necessary funds will not be made available unless management is convinced that there are benefits to be derived. Therefore, whether it is a new program being introduced or an existing one being improved, the first step must be "selling" the program to the organization.

If an organization already has a maintenance management program in place but the program is minimal or there is room for improvement, the process of upgrading may be simplified. However, it may also be complicated by factors such as unsatisfactory personnel preparation, request for system changes, new equipment demands and so on. Therefore, it is advantageous in this report to treat the subject of changes in a system in the same way as the introduction of a new system will be handled.

9.1 Selling the Maintenance Management Program

The development and introduction of a formal maintenance management program must first have proof of its value. It is important that the proposal presented to management shows improvements and justification for the program.

The program should be presented as an orderly way of doing maintenance, with the proper people, tools and materials, at a pre-determined time and with improved equipment availability at the lowest possible cost as the prime objective. The proposal should include, among other things, the following: (7)

1. Current maintenance costs in relation to production.
2. Analysis of operating time losses due to lack of

proper maintenance and a breakdown of where improvements can be made.

3. Data on maintenance productivity in comparison with similar operations.
4. Data on the proportion of PM to emergency work.
5. Evidence that the proposal offers feasible solutions.

It is essential, therefore, that the necessary plan, cost estimates, methods of approach, timetables for expected improvement, and expected cost benefits be included in the presentation. Getting the go-ahead from management to implement the program is the first step in selling the program to the organization.

Once approval has been obtained from management, attention must be focused on maintenance personnel. To establish their committment, it is vital to hold information sessions with supervisors, foremen and maintenance crews, to appeal for their ideas and to be sure that they become "partners" in the venture. (85) After all, it will be a slow process to show improvements in a maintenance program, a five year period is usually involved, and eventual success will depend on the support of this group.

Information sessions should outline the nature of the proposed program, method of implementation, involvement of the different groups, and the benefits and problems to be accepted. Each session should be followed by a question-and-answer period to make sure that personnel understand their responsibility.

Most of all, the program must be presented as a means of improving maintenance performance thereby making daily tasks less difficult. The program should not be presented at this level using manpower control as a major benefit. (85) Though the fact that an improved maintenance effort will be synonymous with better manpower control may appear and certainty should not be denied.

The production department should not be left out at this stage of the program. Production personnel should be acquainted with the mechanics of the program and the role they are expected to play. With these preparations in place, the organization should be ready for the maintenance management program.

9.2 Sequencing the Implementation of a Manual Program

The sequence which is adopted will depend on the nature of the existing maintenance system, how much of a management program is in place, and the management view of the maintenance problem. In any case, the program should be implemented in a phased fashion over a period of time. Figure 9.1 illustrates a suggested sequence.

This is by no means a standard sequence Each maintenance situation will have unique features and the sequence that is most logical for each should be established. Regardless of the sequence adopted, continuity between features should be the main criterion. The following summary explains the sequence suggested in Figure 9.1.

1. Organization and Training

Organization and training is the most logical starting point for almost any maintenance program and applies just as much to upgrading a program as to implementing a new one. A maintenance management program has little chance of success unless it operates in a well organized environment and is manned by suitably trained personnel. In fact, proper functioning of all the other features depends on the support of the organizational framework and the capabilities of the personnel. A logical organization should be adopted, suited to the size and complexity of the operation and to the number of personnel, then levels of authority and lines of responsibility should be defined. Establishment of the organization must be followed by training. Individuals will be selected from the field to fill such positions as planners, schedulers and they must all be trained to use the techniques relevant to their new jobs.

2. Equipment Listing/Item Coding

Having trained the key personnel in the department, they are now equipped to design and develop the many

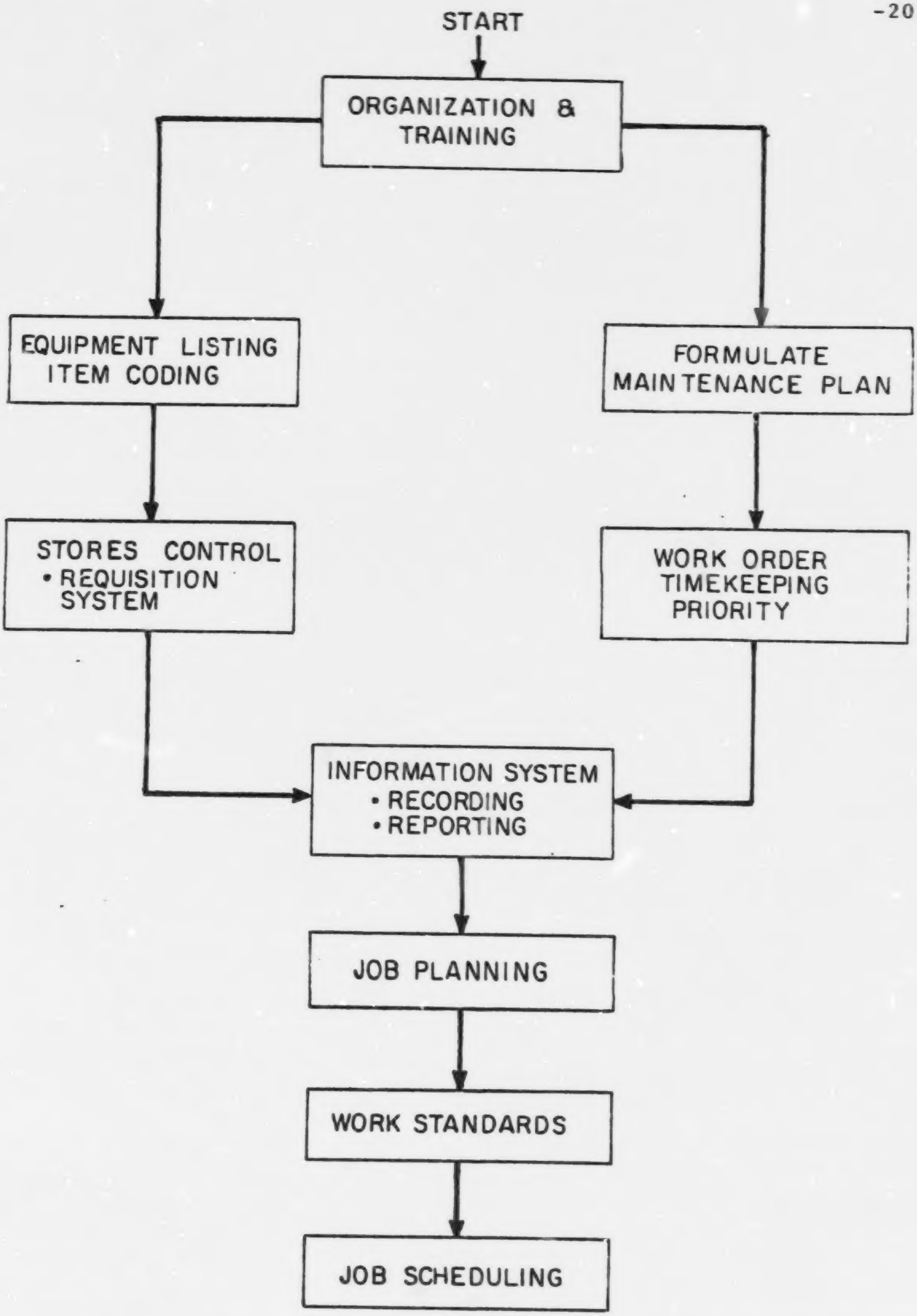

START
ORGANIZATION & TRAINING
EQUIPMENT LISTING ITEM CODING
FORMULATE MAINTENANCE PLAN
STORES CONTROL
• REQUISITION SYSTEM
WORK ORDER TIMEKEEPING PRIORITY
INFORMATION SYSTEM
• RECORDING
• REPORTING
JOB PLANNING
WORK STANDARDS
JOB SCHEDULING

Fig. 9.1 Sequencing a manual maintenance management program (22, 85)

elements of the paperwork system. Equipment listing is the obvious starting point since the program cannot proceed very far without an inventory of the equipment to be maintained. A coding system for critical items and components should also be developed at this stage. Other documents that can be developed at this stage include equipment record cards, and checklists for routine service, lubrication and inspection.

3. Formulate the Maintenance Plan

The maintenance plan can be developed in series or in parallel with equipment listing; preferably in parallel. If historical data is available, it should be used to assist in drafting the plan. In the absence of such data the experience of foremen and supervisors together with subjective judgement will suffice. The plan will have to be updated subsequently as information is generated by the program.

4. Stores Control

The next step should be the establishment or adoption of material control to support the maintennace system. This should involve the establishment of a requisition system and the practice of recording all materials issued from and received by the stores. Stock numbers should be assigned to all stores items and an on-site material delivery system should also by developed. Inventory control techniques can be applied as the system develops.

5. Work Order

The work order system can be implemented either in series or in parallel with stores. (26) This is a good point to introduce the work order since all the features essential to its proper functioning are already in place. The work order should be designed to record and collect all the data required for adequate control of the program. Tied closely to the work order system should be procedures for assigning priorities to jobs and recording the times spent on jobs. A job reporting system can also be implemented at this stage.

6. Information System

Once the work order and the material requisition procedures are in place, information will be generated and the information system can be implemented. It must be designed to collect, organize, analyze, distribute and store data conveniently to be of any use to the operation.

7. Job Planning

The material control, work order and information systems are the three features most essential to maintenance planning. Material control ensures the availability and delivery of material for the execution of jobs; the work order provides the means of requesting and authorizing maintenance work; the information system provides the data that is vital to performing the planning function. With these three features in place, the maintenance is ready for job planning.

8. Work Standards

Efforts can now be directed toward developing maintenance standards. The development of job standards depends on the availability of planned job times to compare with actual job times. With a functioning planning section, this information will be generated. Work measurement can now be introduced to aid in the development of standards.

9. Work Scheduling

Scheduling is by far the most difficult function of maintenance management (85) and, because it requires input from each feature, be attempted when all the other features of the program are in place. It should therefore be the final step in implementing the maintenance program.

9.3 Preparation for Computerization

In this section it is assumed that the organization has had some experience with a manual maintenance management program and therefore would have a good understanding of the system goals and methods to the introduction of computers. However, additional preparation is required for a computerized program. The following is a step-by-step outline of the preparation required prior to computerization: (52, 55, 69)

1. Conduct maintenance audit: A task force

comprising of maintenance, production and data processing personnel, supplemented, if desired, by consultants, should be established for this purpose.

The purpose is to identify maintenance requirements that the computerized system should meet, changes that may be needed (eg. improved work orders), and areas that may need improvement.

2. Conduct survey of computer software: The task force should review programs implemented by other companies and available software peackages. If no software which meet requirements is available, one must be developed.
3. Draw up a new system flow chart: This should have the consensus of all personnel to be connected with the program. It is very important to involve all maintenance supervisors at this stage, or the system will not work well on the shop floor.
4. Review and modify maintenance management procedures, and make any other changes considered necessary. For example, it is usually necessary to redesign the work to include:
   - more specific details than the manual work order
   - more quantitative terms
   - more extensive coding of items and activities.
5. Provide training for all personnel who will be directly involved with the system. Data processing/user training is essential.
6. If not already available, draw up with coding:
   - equipment lists
   - parts lists
   - personnel lists
   - priority lists
   - PM routines lists.

   Even if already available, these lists should be reviewed and upgraded if necessary.
7. Install software or program and test with sample data.

9.4 Sequencing the Implementation of a Computerized Program

An operational computerized maintenance management system usually consists of seven components or sub-systems. They are: (26)

1. Major Sub-Systems
   - Work order entry
   - Job planning
   - Work scheduling
   - Job execution and reporting
   - History and analysis
2. Supporting Sub-Systems
   - Stores
   - Purchasing

The sequence in which these sub-systems are implemented will depend on the nature of existing systems, either manual or computerized. Donnelly, (26) a consultant who specializes in computer applications in the mining and processing industry, recommends the sequence illustrated in Figure 9.2 and summarized below.

1. Inventory Accounting and Control

Stores inventory accounting and control is a logical starting point in a computerized program since it involves the establishment of the Stores Data-Base - the main supporting component of the program. It requires the assignment of stock numbers and the keeping of accurate inventory records and usage history for each item in the stores.

Once a stores inventory data-base is established, control techniques can be applied to determine order points and economic order quantities. Purchase requisitions can also be generated to replenish normally stocked items.

2. Stock Status Inquiry - Purchasing Interface

As soon as the stores data-base is established, it can be put on-line to allow for inquiries on the stock status for individual items. This will greatly facilitate the manual planning system which will still be in place at

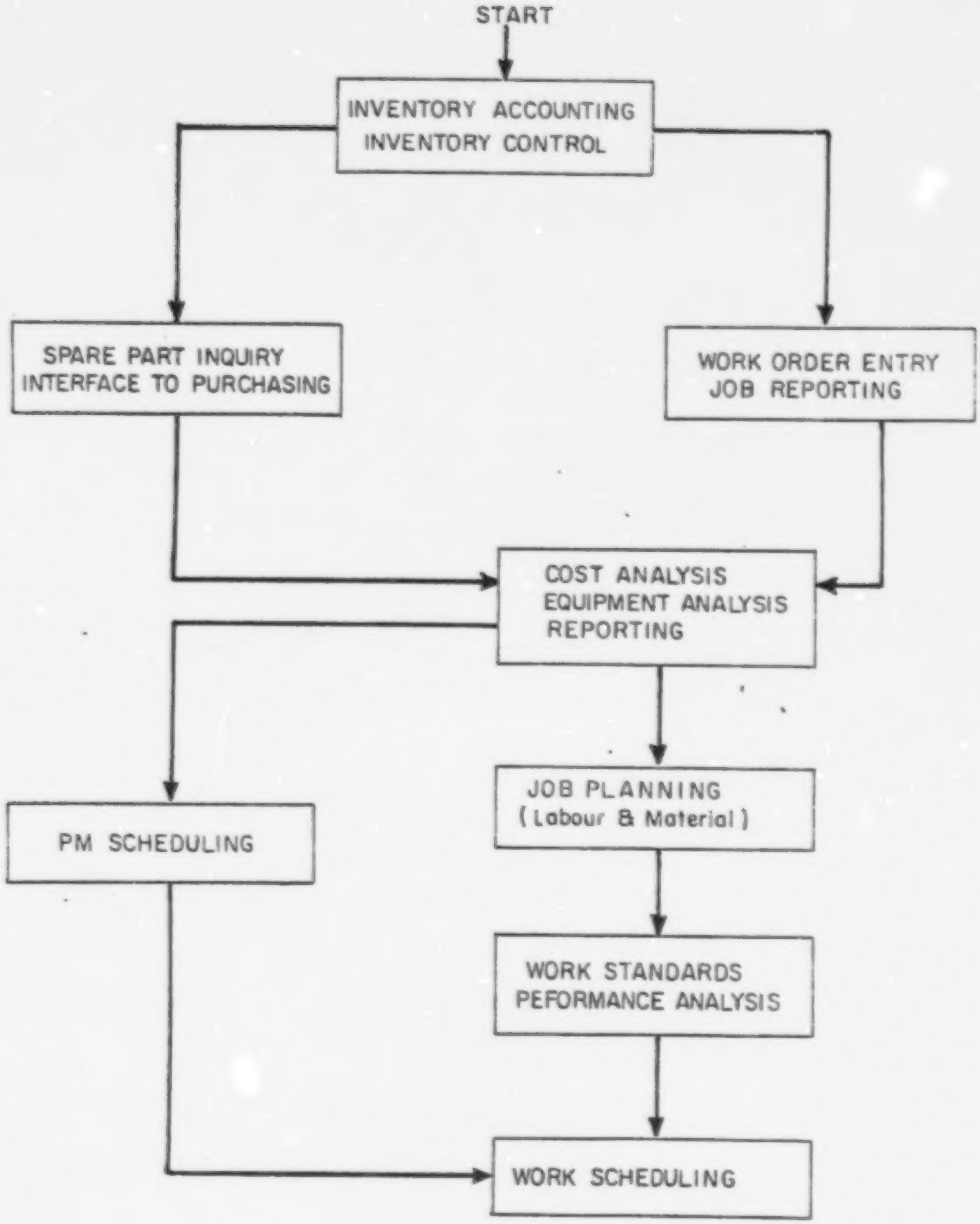

START
INVENTORY ACCOUNTING
INVENTORY CONTROL
SPARE PART INQUIRY
INTERFACE TO PURCHASING
WORK ORDER ENTRY
JOB REPORTING
COST ANALYSIS
EQUIPMENT ANALYSIS
REPORTING
PM SCHEDULING
JOB PLANNING
(Labour & Material)
WORK STANDARDS
PEFORMANCE ANALYSIS
WORK SCHEDULING

Fig. 9.2 Sequencing a computerized maintenance management program (26)

this stage.

The next step can be to provide an interface between stores and purchasing. If a purchasing system does not exist, such a system must now be considered.

3. WO Entry and Job Reporting

The work order entry sub-system can be implemented either in series or parallel with stores and purchasing. It should allow for entering job requests in an interactive manner using available visual display terminals. This establishes a data base for open work orders.

Since job reporting is closely associated with work-order entry, it can be implemented at this stage. Job reporting can be accomplished by telephone and/or radio, or by recording information on the job ticket. With this procedure, open work orders can be closed and accurate information can be accumulated.

4. Equipment/Cost Analysis and Reporting

Because an equipment number is normally specified when a work order is entered, it is appropriate to establish the equipment data base at this time. This will require coding equipment items and components and entering the initial information into the system. With an already prepared equipment list, this should be a simple exercise that will facilitate equipment analysis and the beginning of job planning.

Cost analysis and reporting are directly linked to work-data entry and job reporting. These capabilities can now be introduced into the system. Cost can be reported by cost centre and/or type of equipment and an on-line inquiry capability can be provided.

5. Job Planning

By giving the planning section access to the stores inventory and equipment data bases, job plans can begin to be developed. These plans will be simple at first, providing only the material and skills required to perform the job. However, as information is generated and stored, they will become far more detailed. As job plans are developed, they will be stored by the system and a library of job plans will be developed.

6. Work Standards - Performance Analysis

From the available library of job plans, work standards can be extracted. Once work standards are established, it is possible to compare the actual and planned acitivity to analyze and report performance.

7. Preventive Maintenance Schedules

The next step can be to generate and update preventive maintenance schedules. This is possible at this stage because the system can now provide predictive information through analysis of equipment history and performance.

8. Work Scheduling

Work scheduling depends on the availability of job estimates. In job planning, estimates are made of labour requirements; once this is done, jobs can be accumulated, arranged by priority and scheduled according to the availability of maintenance manpower. The system can then summarize the labour requirements for all areas and compare them with expected availability.

9.4.1 Implementation Overview of an Actual Program

The sequence illustrated in Figure 9.2 and summarized above does not have to be followed in every case. Although it is based on experience, (26) it may not necessarily apply in every situation. The sequence is indicated to show the logic that is involved in sequencing a computerized maintenance program. Moreover, the above sequence is best suited to situations where a suitable software package already exists, and all that is necessary is the logical sequencing of the different sub-systems.

However, occasionally, available software packages do not meet the specific maintenance requirements of certain operations. In such cases a program, making full use of available computer technology, must be designed. This was the case at the Kennecott Minerals Company (KMC) (52) in Utah, U.S.A. KMC operates three active open pits, associated

Table 9.1 Implementation Overview of an Actual Computerized Program (52)

1960	Cost and Work Order System
1964	Haulage Truck Service Scheduling and Component Monitoring (P.M.) System
1969	Haulage Truck Tire Analysis System
1971	Material and Supply (Inventory) System
1972	Expanded P.M. System
1975	Beginning of development of interactive systems
1976	Equipment Specifications Spare Parts Lists (Bill of Materials) Equipment Cross Referencing Spare Parts Inventory Status
1977	Equipment Histories Overhaul Standards Work Order Backlog Work Order Cross Reference Locomotive Service Scheduling and Component Monitoring
1978	On-line Cost Analysis P.M. Requirements (Smelter)
1979	P.M. Craft Leveling (Smelter) P.M. Manhours Summaries (Smelter) On-line Haulage Truck Tire and Rim Analysis System Equipment Downtime Statistics
1980	Equipment Availability Analysis Lubrication Scheduling and Routing (Refinery) Purchasing Specifications Inquiry Electric Motor Cross Referencing
1981	P.M. Scheduling (Smelter) On-line Mine Equiment Component Analysis Mine Equipment Component Failure Forecasting Oil Analysis Tracking System
1982	Automatic Spare Parts Ordering P.M. Backlog Tracking (Smelter) Overtime Tracking and Callout System Plant Equipment Component Changeout Scheduling and Analysis (Concentrator)
Future	On-line Work Order Generation Craft Requirement Forecasting based on scheduled work orders, overhauls, and preventive maintenance

reduction plants, and a copper refinery. The combined operations have in excess of 600 pieces of mining equipment and 2000 pieces of plant equipment. As mentioned in Chapter 7, KMC has the most comprehensive, computerized maintenance management program, encountered in the literature. It is therefore used as an example, to illustrate the sequencing process of a self-designed computerized program, and most of all, the kind of time frame involved.

At KMC, computers were used to assist maintenance management as early as 1960. However, until 1975, it was a batched system, using a single job-entry station and a dialup telephone link to a central computer center. The present system, whose implementation commenced in 1975, is continuous, interactive, and self-prompting. Table 9.1 presents an overview of the system implementation which shows that even after seven years (1975-1982), KMC still did not have a complete system. Additional features which are currently under development include: (52)

- on-line work order generation
- craft requirement forecasting based on scheduled work order, overhaul and preventive maintenance.

Even with the above deficiencies, it still appears to be the most comprehensive system employed by a mining operation.

9.5 Upgrading the Maintenance Management Program

What is the condition of your maintenance management program? The answer to this question should interest every level of management, from the executive level to the maintenance management level.

An operational maintenance management program has little chance of success unless provision is made for continual monitoring and assessment of its effectiveness. At least once a year (23,54) or at a frequency deemed most suitable for the operation, the general condition of the maintenance program should be evaluated. The different elements of the program should be appraised with the aim of identifying weaknesses and developing specific plans to upgrade same.

9.5.1 Appraising the Program

Assessing the effectiveness of a maintenance management program is not simple and the fact that each level of management views the program in a slightly different light, does very little to facilitate the process. (68) Top management feels that the program is effective if there are no stoppages in production and if maintenance expenditure stays within the budgeted limit. Middle management feels that once there is a speedy response whenever a piece of equipment fails, then the program is doing a good job. Maintenance personnel feel that fewer emergency work requests and not having to account for frequent equipment failures, are good indications of effectiveness.

Regardless of the differing views, answers are usually required to such questions as:

- How is the maintenance program performing?
- Is its performance in line with overall objectives?
- Does it provide coverage to all aspects of the operation?
- Are there areas or elements in need of upgrading?

The answers to these questions can be obtained in several ways:

1. by employing a consultant
2. by using a team of staff specialists to conduct a survey and produce a report
3. by completing a check-list appraisal (36, 55, 84) (see Appendix A).

Methods 1 and 2 are very common to the industry but they are expensive and time consuming. Method 3 allows a quick and valuable appraisal of the maintenance management program at the least cost. (36)

The check-list (questionnaire) presented in Appendix A was developed after a comprehensive literature review and covers all essential element of a maintenance management program. Essentially, the questionnaire is so structured that a complete appraisal is only possible if participation is solicited from the three levels of management within the operation. It is stratified into three levels of management with each level being assigned specific responsibilities to the program. Top management (executive level) is assumed to be responsible for establishing and setting maintenance policies and objectives; middle management (manager, superintendent, engineer) are assumed responsible for developing, implementing and monitoring the program; and maintenance management (front-line supervision) for execution and supervision of day-to-day activities.

How the questionnaire is used depends on the purpose of the appraisal. In situations where a maintenance program is being developed, the questionnaire can be used simply as a check-list, to determine what elements constitute a maintenance management program. In situations where a program has recently been introduced, the questionnaire can be used to determine completeness. By awarding answers of "Yes" or "No" to each question, the user can identify those elements that have been omitted.

In established, operational programs the questionnaire is used to pinpoint weak areas. In these cases, awarding answers of "Yes" or "No" is not enough; a scoring system must be established. Each section is assigned a par score, the magnitude of which depend on how critical the section is considered to be. Such a system will vary from program to program, however, having established one, it is used as a basis for comparing, actual scores which are awarded in accordance with estimated accomplishment in the different areas.

The questionnaire is for record-keeping purposes. It may be used repeatedly so it is important to know who is doing the answering in each case. Again, from time to time, maintenance managers from different operations may get together and during such meetings, it is often desirable to make comparisons of one kind or another. The questionnaire can well serve as the foundation for such comparisons by focusing discussion on agreed problem areas.

Results of the questionnaire appraisal will offer all levels of management an indication as to where maintenance management needs strengthening. This questionnaire is, categorically, not a panacea intended to cure all the ills of a maintenance program; it is designed only to identify weak areas that require further investigation and subsequent corrective action.

9.5.2 Improvement Program

Generally, identification of a problem is half its solution. Having appraised the maintenance management program, and assuming weak areas have been identified, further investigation must be carried out to evaluate the degree of improvement necessary to upgrade the respective areas to the required level.

A number of methods can be used to evaluate deficiencies in identified areas. Any of the performance measurement methods discussed in Chapter 6 will serve this purpose and in applying these methods, the choice of the index in the particular area should be decided by each operation. It is also necessary to establish standards or targets to which index values can be compared. There is some evidence that work sampling can be applied to certain areas.

Having identified weak areas and evaluated their deficiencies, corrective actions must be prescribed - what is to be done, who is to do it, and when it is to be done. Next, an improvement program establishing the sequence and timing of all recommended corrective action should be developed. This must be accompanied by cost estimates since management cannot justify spending money to upgrade the maintenance program unless estimates of savings and benefits are provided.

Implementing the improvement program is the next step. A meeting should be held with all maintenance and production supervisors and representatives of top management. (23) Attendance by top-level managers is especially important, to convince maintenance personnel of management's interest and commitment to the improvement of the maintenance management program. The meeting should review the deficiencies found in the program and discuss the changes to be implemented, the reasons for them, and benefits and problems expected. Personnel should also be allowed to have inputs to the program at this stage.

Regardless of the areas being upgraded, the improvement program must include: (22, 23)

- a review of personnel performance
- further training of weak personnel
- a review of maintenance systems and procedures
- a review of the information system
- continual monitoring of progress.

9.6 Conclusion

Implementing a maintenance management program can be one of the most difficult tasks of the maintenance manager. This is primarily because, in the majority of cases, he will be attempting to change the way that things (maintenance actions) have been done for a number of years, usually a change from a crisis approach to a systematic one. The method of approach to implementation will determine the outcome of the proposed program.

It is important to remember that the pace of implementation will have a significant effect on how well the program is received and how well it is appreciated. Whether a new systematic program is being introduced or whether an established program is being upgraded, the process must be gradual - one step at a time. (85) Moreover, the program should be implemented in a phased fashion over a number of years. (26) The primary obstacle to faster implementation is how quickly maintenance personnel can accept and adapt to a new way of doing things. Individuals may learn quickly but time is required for a system to become established as a smooth functioning entity.

During implementation, many items will need attention and the maintenance team will attempt to get them all done at once. But care should be taken not to introduce so many elements that loss of control results. By introducing one element at a time, better control can be maintained over the system and there will be no need for backtracking which can lessen or destroy confidence in a system.

Moreover, it is imperative that computerization not be used as an end in itself. It is only a means to an end and should only be applied after sufficient manual control is in place. Even more important, the computer should not be used to control the program but to assist maintenance personnel in achieving better control.

Finally, a maintenance management program should not be implemented until the entire organization is fully prepared and totally dedicated to the cause. (85)

Chapter 10

THE STATE OF MINE MAINTENANCE MANAGEMENT IN CANADA

The previous chapters have outlined, the various features of a mine maintenance management program including preparing for the program, developing the program, computer application, and implementation. Also outlined are the various practices and techniques that have been used, at large, in managing maintenance and that have been found to be successful.

In this chapter the current state of maintenance management in the Canadian mineral industry is discussed, essentially, as an outline of findings from an assessment of actual programs. The findings are based on interviews and examination of relevant documents made available during a recent survey of twelve mining operations. The duration of the visits varied between 2 - 3 days and personnel interviewed ranged from vice presidents to shopfloor workers.

During the review of the different maintenance operations, the following activities were undertaken:

- The facilities for operations and maintenance at the mine and mill were toured and first-hand discussions were had with the operations and maintenance workforce.

- Interviews were held with the key maintenance, operations and stores personnel to assess the adequacy of the maintenance systems, procedures and policies. Opinions of the users were also solicited.

- Available documents including WO's, checklists, material requisitions and record cards were examined to evaluate suitability to both systems and potential systems.

- Organization structure and reporting relationships were reviewed to determine their effectiveness.

- Information system and control procedures, including costing and budgeting, were analyzed to determine the level of understanding and the use that is made of informaion in maintenance decision-making.

- Systems and procedures used by each central "control unit" were reviewed.

The activities undertaken at each operation depended on the personnel and documents that were made available and varied from property to property. However, in each case, the activities reviewed allowed a fair assessment of the maintenance management features and the overall impressions obtained for each property were approved as reasonable by the senior managers.

10.1 Supporting Features

These are the features, largely independent of the mechanistic aspects of a maintenance program that must be in place to support the maintenance management program. They are essentially attitudinal in nature and reflect the company's attitude towards maintenance. That is, they indicate the seriousness with which the organization views maintenance management.

Supporting features, by large, represented the weakest feature reviewed during the field survey.

a) Attitude

This feature can best be described as changing, evident by the fact that all the companies surveyed have some form of a systematic maintenance program in place. However, as the following questions and answers illustrate, there is much room for improvement in a large percentage of the participating companies:

1. Top Management

- Are there clear written maintenance objectives?

Yes - 16%
Some - 8%
No - 76%

- Are there clearly established maintenance policies?

Yes - 8%
Some - 8%
No - 84%

- Is maintenance truly represented at the decision-making level?

Yes - 33%
I think so - 42%
No - 25%

- Is this level informed (reported to) on the performance of maintenance?

Yes - 33%
Sometimes - 42%
Not enough - 25%

- Is interest shown by this level to the problems of maintenance?

I think so - 67%
Not enough - 33%

- Has an audit or appraisal of the MMP ever been requested?

Yes - 16%
No - 84%

2. Middle Management

Interviews at this level revealed that most middle managers recognize and appreciate the need for a systematic approach to maintenance management, however, the vast majority blamed top management for the lack of the attitudinal and financial support required. The following questions and answers illustrate:

- Is there a need for improved maintenance management in the company?

Yes - 75%
No - 25%

- How would you rate the current MMP?

Good - 16%
Mediocre - 59%
Crude - 25%

- What is the main hindrance to the improvement of the MMP?
  Top Management's Attitude - 67%
  Front Line Management Attitude - 25%
  Organizational Attitude - 8%

- How would you describe top management's attitude to maintenance?
  Positive - 33%
  Changing - 25%
  Negative - 42%

- How would you describe front-line managers' attitude to maintenance?
  Positive - 25%
  Changing - 59%
  Negative - 16%

- Is maintenance truly represented at the executive level?
  Yes - 33%
  No - 67%

- Is enough interest shown by the executive level to the problems of maintenance?
  Yes - 16%
  Changing - 42%
  No - 42%

3. Front-line Management

Interviews at this level revealed that managers do have a negative attitude to planned or systematic maintenance and that it was mainly because they were exposed to the old school of thought - operate to failure or breakdown maintenance - and are ignorant of the requirements and mechanics of planned systems. Many front-line managers are not properly trained to understand and appreciate new systems that might be or have been introduced.

Further to the above, managers at 42% of the companies believe that their approach to systematic maintenance is wrong. They claim that they are not involved enough at the initial setting up of systems and are required to perform too much paperwork on a day-to-day basis.

b) Objectives and Policies

These are vital to the success of the maintenance management program as they allow the administration to convey to all parties involved what is expected of maintenance and how these expectations are to be achieved. As explained in chapter 2 of this report, clear maintenance objectives and policies provide an operating charter that serves management, maintenance and production, allowing each to be aware of the performance of maintenance at any point in time.

For companies participating in the survey, clear maintenance objectives and policies are virtually non-existent. Only 16% of the companies have attempted to establish objectives and only 8% have policies. Even in this small group, policies and objectives lack detail and clarity and are not tailored to the needs of the individual operation. They are largely the results of consultants' studies and are very general in nature.

Many middle managers agreed with the need for clearly established objectives and policies, but argued that their establishment is the responsibility of top management. On the other hand, top managers argued that everyone concerned should know what is expected of maintenance and many questioned the usefulness of established maintenance objectives and policies.

However, there is some evidence that the absence of maintenance objectives and policies in many of the operations is affecting the performance of existing programs. Many of the front-line managers have confessed that they continue to repair equipment regardless of the cost because their basic objective is to keep the machinery running. They have no knowledge of such maintenance cost objectives as "ensure equipment availability at reasonable cost" or "provide maintenance service within the limits of a budgeted amount." Maintenance service is therefore provided to avert breakdowns at any cost.

As far as policies are concerned many programs have begun to falter because of the absence of clear policies. For example, at one operation a systematic maintenance program was recently introduced and, in the opinion of all parties, it was a good program and there was no reason why it should fail. However, very early in the implementation stage, front-line managers' attendance at planning, scheduling and updating meetings dropped from 80% to less than 40%. Attendance continued to deteriorate and at the end of the first six months it was down to 25% and middle managers had no way of forcing attendance because there was no clear policy which made attendance at the meetings mandatory. Complaints to top management yielded no positive response. As a result, middle managers became frustrated and their efforts to implement and monitor the program began to diminish. This is just one of several examples where the absence of maintenance policies was observed to be affecting existing programs.

c) Total Life-cycle Maintenance

This feature is present in about 67% of the programs reviewed but, even in these, the total life-cycle approach is only partly applied. If Figure 2.2 is used as a guide, there is no company which has a complete total life-cycle program ie. no program covers the range of activities illustrated in Figure 2.1. Moreover, there is little indication of on-going liaison between the companies and equipment suppliers; suppliers' visits are restricted to sales and user training.

The majority of the operations emphasize only two stages of the life-cycle, commissioning and replacement, apparently because many managers have little knowledge of what total life-cycle maintenance involves. Performance monitoring during the commissioning stage is conducted mainly to justify warranty claims and there is little indication that the practice is carried over to the operating period.

One area of exception during the operating life of equipment is that of tires. Many companies have sophisticated tire-monitoring program because of the high deterioration rate of the item and the high cost involved.

Capital equipment replacement is another area where big differences exist among the companies. Very few companies have explicit replacement practices and even these do not utilize some of the current techniques available. Moreover, many managers expressed dissatisfaction at maintenance input into replacement decisions. In a large majority of the companies these decisions are the exclusive responsibility of top management. Very few companies make use of the computer in replacement decision-making. In the majority of cases manual methods are used and they are based on experience because of the lack or shortage of suitable data to aid the decision process.

However, there are indications of changes taking place. Two companies have embarked on programs aimed at improving the total life-cycle approach. Programs, very much similar to the one illustrated in Figure 2.2, were drafted and the co-operation of suppliers was solicited. Managers at both operations claimed that it is not the first time such an attempt was made and that previous failures were due to suppliers' attitude. Response from suppliers concerning the current programs was not available at the time of the visits.

Nowhere is the total life-cycle approach more desirable than in the management of mine maintenance. The dependence of life-cycle profitability on availability, and hence on maintenance, has greatly increased as mining equipment has become more sophisticated but it is clear, from the companies visited, that the importance of life-cycle maintenance has not yet been recognized. Therefore, it is imperative that some awareness be generated in this area.

d) Maintenance Annual Report

Very few of the companies have a separate maintenance annual report. In fact, only 16% of the companies were in a position to make such a report available for examination.

Many of the companies have a monthly maintenance report and managers are required to accumulate these to make an annual assessment of maintenance performance. This group of monthly reports is no substitute for a comprehensive annual report since they are solely concerned with reporting maintenance performance; there is no mention of long- and intermediate-term plans, capital projects and requirement forecasting. In a number of cases monthly reports do not reach the executive level and even when they do, very little attention is paid to their contents.

Some companies include a maintenance report as part of the overall operation's annual report but this practice, again, does not suffice. An examination of many of these reports revealed that vital maintenance information is lost among production figures and it would take a very astute maintenance executive, with a considerable expenditure of time, to extract meaningful data. Moreover, this kind of annual maintenance reporting does not give maintenance the kind of opportunity it requires to express its intentions and requirements. It robs the function of that separate communication link with the executive suite, together with the fact that the joint presentation of production and maintenance data encourages the production biased executive to disregard the maintenance information.

e) Maintenance Management Manual

This is one of the more important features in the supporting group since it allows the administration to express the workings of a program and to encourage on-going training of personnel. It is also the primary medium for clearly spelling out maintenance objectives and policies, and the functions and responsibilities of the people involved. Many of the participating companies agreed with these statements, but:

25%, only, have an up-to-date, complete manual
40% have a manual that is out-of-date, and
30% have no manual at all.

Of the companies having manuals, it was found that:

25%, only, have a manual tailored to their needs, while

75% have manuals that are general in nature.

All the "general" manuals were produced by consultants and though they were complete in terms of coverage, they essentially explained the concepts of systematic maintenance and were not designed for the particular needs of the operations. For example, the manuals of two very different operations were examined and they are essentially identical.

Companies with no maintenance management manual have the weakest programs. Managers and workers alike have little knowledge of the program and even less of the roles they are required to play. A slightly improved situation exists in those companies with out-of-date manuals.

10.2 Essential Features

These features (see section 1.2) are fundamental to the functional maintenance management program; the objectives of systematic maintenance cannot be achieved unless the program is based on the development of these features. Each feature is an individual element of the program but, because of the many inter-relationships, they must be developed as an integral whole. The extent to which each feature is developed and applied, in the particular situation, determines the strengths and weaknesses of the program.

This section outlines the status of the essential features of existing maintenance management programs, in the participating companies of the survey. Emphasis is placed on highlighting strengths and weaknesses and results are based on users' opinions, observations and comparisons to information in the literature.

a) Organization

This is the primary essential feature of the maintenance management program but observations and discussions revealed that it does not receive the kind of attention it rightly deserves. Within the organizational structure, maintenance is still regarded as subordinate to production. This view is supported by:

- top managers at 33% of the companies
- middle managers at 67% of the companies
- front-line managers at 83% of the companies
- maintenance workforce at 83% of the companies.

Middle managers are very dissatisfied with the level of support and attention given, by the executive level, to the maintenance function. Front-line managers feel that they are not regarded as equal to their production parallels. There is, generally, a strong feeling that maintenance has a far way to go before it is considered an intrinsic part of operations.

The other aspects of maintenance organization vary significantly among the companies but most companies require improvements in a number of areas as illustrated below:

1. Department Structure
    - Fully defined functions - 67%
    - Loosely defined functions - 25%
    - Badly defined functions - 8%
2. Staffing - Supervisory
    - Adequately staffed - 92%
    - Inadequately staffed - 8%
3. Staffing - Administrative
    - Adequately staffed - 42%
    - Inadequately staffed - 42%
    - Badly staffed - 16%

The main problem in the administrative area is the "control unit" or "work control group." Most companies do not have a "control unit" and those that do are not too sure how it is to be organized and staffed. Control units are performing predominantly clerical functions and lack such analysts as expediter, material coordinator, cost analyst and PM coordinator. Emphasis is placed on area control but there is no group for coordinating area activities.

4. Training - Workforce
   - Formal - 33%
   - Informal - 59%
   - Little training - 8%

Most companies rely on informal training for maintenance workers but many managers feel this is inadequate to produce the calibre of skills required. The common complaint is the unavailability of funds to conduct comprehensive training programs. In over 67% of the companies there is no formal training for front-line supervisors and administrative staff. Unquestionably, in view of the current limited use of the desirable management systems, there is a total lack of training capability for early adoption of those systems.

6. Maintenance Production Relationship
   - Excellent - 16%
   - Good - 42%
   - Poor - 42%

The major problem in this area is the refusal by production supervisors to comply with PM schedules. The relationship is very poor in those companies that permit contract work by production personnel which means that the benefits associated with contract work almost certainly have a hidden cost in higher maintenance costs.

7. Workshops and Facilities
   - Excellent - 42%
   - Good - 42%
   - Poor - 16%

Many companies have very good workshops and facilities but organization and location are poor. This results in under-utilization of the workforce and slow receipt and delivery of components.

b) Systems and Procedures

Several companies have very sound systems and procedures but they are not being applied in the correct manner.

Many of the basic documents such as the work orders, material requisitions and equipment cards are well designed but they are not used to achieve the desired result - maintenance control. Good examples that highlight the problems with this feature include:

1. Work Order

All the companies in the survey have a work order system but very few have an effective one. Many use the work order only for work requisition with little effort to achieve work control. Of the companies surveyed, only:

16% have an effective work order system
25% have a mediocre work order system, and
59% have a very poor work order system.

Some of the common problems in this area include:

- poor work order engineering
- poor work order job-reporting
- poor work authorization
- limited priority procedure.

2. Stores

The survey indicates that most of the participating companies have very poor control over maintenance stores, perhaps because maintenance stores is not the responsibility of maintenance in any of the companies. As outlined in section 4.2, maintenance should have control over its materials and spares, so it can blame no one but itself for poor stores service. Many participating managers disagreed with this concept but yet, they blame the stores system for many of maintenance's problems. In essence, the opportunity to avoid responsibilities appears attractive.

Some specific maintenance stores problems are listed below:-

- poor stores inquiry system
- no materials availability check prior to issuing work order
- limited deletion of obsolete inventory items

- poor interfacing with purchasing.

3. Maintenance Standards

The following questions and answers illustrate the status of this element:

- Are there labour time standards covering repetitive jobs?

Yes - 8%
No - 92%

- Are job times recorded for the establishment of standards?

Yes - 33%
No - 67%

- Are certain job methods standardized and documented?

Yes - 42%
No - 58%

4. Budgeting

The following questions and answers illustrate the status of this element

- Is there an established budgeting procedure?

Yes - 75%
No - 25%

- Does the procedure involve every level within the department?

Yes - 58%
No - 42%

- Is historical information used to aid budget projections?

Yes - 16%
Partly - 25%
No - 59%

5. Critical Problem Procedure

An established written procedure was available and was examined at 16% of the companies. Many of the other companies claimed that a procedure was in place but no documented evidence was made available. Deficiencies in the area must be inferred.

c) Maintenance Strategy

Most companies have a good start on their PM program, but very few have established corrective maintenance procedures. Managers are generally dissatisfied with current results of PM work and they blame the situation on such factors as a lack of production co-operation, insufficient historical data, poor analysis of available data, limited use of diagnostic maintenance and poor updating of PM program.

The following questions and answers illustrate the PM situation in the participating companies:

- Is there an up-to-date equipment register?
  Yes - 67%
  No - 33%

- Is all equipment identified with a code number?
  Yes - 50%
  No - 50%

- Are items and components classified by criticality?
  Yes - 16%
  No - 84%

- Are there up-to-date equipment history cards?
  Yes - 42%
  No - 58%

- Are there standard work orders for routine maintenance tasks?
  Yes - 67%
  No - 33%

- Are PM procedures well established?
  Yes - 50%
  Partly - 8%

No - 42%

- Is there a "trigger" system for automatic generation of PM orders?

  Yes - 50%
  Partly - 8%
  No - 42%

- Is all key equipment covered by the PM program?

  Yes - 50%
  No - 50%

- Is there cost comparison data for individual pieces of equipment?

  Yes - 16%
  Some - 8%
  No - 76%

- Are there specific PM budgets for major pieces of equipment?

  Yes - 33%
  No - 67%

- Are you satisfied with the current PM program?

  Yes - 33%
  No - 67%

- Is safety an integral part of the maintenance strategy?

  Yes - 84%
  No - 16%

d) Planning and Scheduling

Many companies are not satisfied with their present planning and scheduling procedure. Most of the maintenance planning is done by the maintenance foreman and the planner performs predominantly clerical functions; very few planners actually engineer the work order. In a number of companies the planner merely receives and writes up the work order, dispatches it via a loading board and, on its return, extracts and records useful information.

Participants agreed that effective planning and scheduling is required to provide the base for proper maintenance performance. However, many reported that they lack the calibre of personnel who can effectively perform the function.

Planning and Scheduling was observed to be done by:

Foreman - 75%
Planner - 25%

The following questions and answers further illustrate the situation in the maintenance planning and scheduling area:

- Are work orders engineered prior to issue?

Yes - 25%
Partly - 33%
No - 42%

- Is the work order priority system applied to all work?

Yes - 33%
No - 67%

- Is there at least one day's work planned ahead?

Yes - 75%
No - 25%

- Are most jobs completed in line with the planned dates?

Yes - 42%
No - 58%

e) Information and Control

This is by far the weakest feature in the essential feature group. Most companies have a fair information system, but very few make effective use of the acquired information to effect maintenance control. In fact, of the twelve participants of the survey, only two have displayed some control of the maintenance function and in both cases it was rated at between 55%-65% by the respective users. The other companies have some form of systematic maintenance but not maintenance control.

Similar to the situation that exists in the planning and scheduling area, there is an obvious shortage of personnel who can effectively analyze historical maintenance data and then apply it to effect maintenance control. Moreover, among the participants, there is limited knowledge of the methods and techniques that are used for these purposes. There is definite room for improvement in this area.

The following questions and answers illustrate the situation in the information area and the severe lack of maintenance control.

- Is there an information system that permits the acquisition of useful data?

  Yes - 58%
  No - 42%

- Is sufficient data accumulated to assist in the control of maintenance?

  Yes - 16%
  No - 84%

- Are reporting procedures adequate to permit information flow?

  Yes - 33%
  No - 67%

- Is historical data used to assist decision-making in certain areas?

  Yes - 16%
  Partly - 42%
  No - 42%

- Are weekly/monthly productivity reports prepared and issued?

  Yes - 33%
  No - 67%

- Are accurate work backlog records maintained?

Yes - 42%
Partly - 33%
No - 25%

- Is backlog data used for manpower planning?

Yes - 16%
No - 84%

- Are there weekly/monthly reports showing cost trends of maintenance work?

Yes - 75%
No - 25%

- Are cost trends used to aid cost control of maintenance activities?

Yes - 25%
Partly - 8%
No - 67%

- Is downtime control a part of the PM program?

Yes - 8%
Partly - 25%
No - 67%

- Is quality control a part of the PM program?

Yes - 8%
Partly - 8%
No - 84%

- Is maintenance performance regurlarly reviewed and analyzed?

Yes - 16%
No - 84%

10.3 Additional Features

In this section the features of computerization, analytical techniques and implementation are discussed. These are not essential features in the same sense as those discussed in section 10.2, but in today's mine maintenance environment, they play a vital role in the attempt to achieve maintenance control.

a) Computerization

With one exception, all the participating companies in the survey employ some degree of computerization in the management of maintenance. The computer is mainly employed in the areas of stores inquiry, information storage and PM scheduling with minimum application in such areas as work order generation, reporting and control. Most companies, correctly, use the computer as a data library, however, once the information goes in it is not utilized to justify its input in the first place. Very few companies, for example, generate regular equipment histories and, even those that do, make minimum use of the information. Even fewer companies generate meaningful information reports from the data stored in the system.

The basic problem is twofold: some managers, especially front-line, are fearful of the computer because they lack the background as to its workings, the role it plays in the program and how it can be effectively utilized; other managers, mainly middle, lack the know-how to set-up and provide the training required to successfully sell computerization to maintenance.

In addition to the above, there are the problems of preparation and implementation. As mentioned in section 9.3, additional preparation is required prior to the indtroduction of a computerized program and this assumes that maintenance has had some experience with a manual program. If a manual program is not in place or the one in place is not functional, then the maintenance department is not ready for computerization and any attempt to introduce same will yield minimum benefits. Moreover, how a program is introduced and how its sub-systems are sequenced, determine how successful the program will be.

Many companies, about 84% of them have poor preparation for and poor implementation of their computerized maintenance programs. Some of the common faults are:

- the existence of a weak manual program, lacking many features
- the adoption of computerization with little input from maintenance
- poor sequencing of sub-systems in implementing the system
- poor preparation in the areas of maintenance audit, personnel training and systems modifications
- poor structuring of the system in terms of its interactive nature, data base structure and input and output features.

As a result, the majority of the programs are:

- not benefiting the maintenance department
- used as a batch system instead of an on-line, interactive system
- under-utilized by maintenance personnel.

Although it is encouraging to see many companies recognizing the need for computerized maintenance management, there are still many problems in this area. Very few companies have employed consultants to assist in implementing their programs and many are user-developed using the services of internal systems analysts. Although these are acceptable approaches, it has not been recognized either that it is a long-termed effort or that the different features must be sequenced to produce continuity and familiarity. That is, the human training and experience requirements of the systems have not been appreciated.

b) Analytical Techniques

The situation in this area is best illustrated by the following questions and answers:

- Are work study techniques used for developing maintenance time standards?

Yes - Nil
Partly - 8%
No - 92%

- Is work sampling or work measurement used to measure maintenance performance?

  Yes - Nil
  No - 100%

- Is CPM used to assist the planning and scheduling of large jobs?

  Yes - Nil
  Partly - 16%
  No - 84%

- Are operations research techniques used to assist maintenance decision-making?

  Yes - Nil
  Partly - 8%
  No - 92%

Some managers have limited knowledge of the analytical techniques that are applied to the management of maintenance, however, in the reviewed programs, none of these are employed to any appreciable degree.

c) Implementation

This feature is in very much the same situation as that of computerization. Most companies are not aware of what is involved in implementing the maintenance management program and many programs have been implemented into an organization/department where the personnel are totally unprepared for its introduction.

As mentioned in chapter 9, regardless of how good a MMP may be, if it is not properly sold to the organization, it will fail. Many of the problems and failures observed and reported by the participants are directly linked to poor implementation.

Only 16% of the companies reported real top management involvement in the implementation of the MMP and these are the same companies that reported good top level support and whose programs are superior to the others. A higher percentage of the participants reported front-line management involvement but this appeared to have been superficial since many supervisors and administrators were dissatisfied with their involvement at this stage. There was minimum involvement of the workforce, at this stage, in the majority of the programs.

Overall, 84% of the programs were poorly implemented. Apart from inadequate personnel involvement, most programs are poorly sequenced and there is little performance appraisal for program improvement.

10.4 Evaluation Validity

This investigation was instigated, in part, at the request of the mineral industry and was organized and carried out without precedents on which to base sample size, scale and so on. In view of the strong indication of shortfalls in maintenance management that have resulted, it is only prudent to reflect on the adequacy of the investigation. Basically, was the approach valid or was it merely an academic effort without practical orientation? was the sample of the industry adequate and appropriate? and are there implications for subsequent work that should be identified?

First, the approach was academic only in the sense that it was conducted from a university and that the review plan that was used was based on a literature survey. In fact, the bulk of the published reports were from industrial operations including consultants in maintenance management; as a result emphasis has been based almost exclusively on practical experience. Even the techniques that have not been widely used in mining have been proven for other industries; they are not at all untried. Secondly, the results from field visits have not been interpreted so much as reported. It is clear that the investigation has had a predominantly practical orientation.

The sample of the industry is, admittedly, limited if only because so many criteria exist against which representation could be gauged. The sample aimed to examine hard rock and continuous mining, open pit and underground mines, bulk and selective mining, large and small operations, geographical locations and a range of commodities though, obviously, not all of these features were tested in only 12 mines.

On the other hand, the mines visited account for about 10% of Canadian mines, over 10% of mine production, and a wide range of types, scales, commodities, location and ownerships. In fact, if the sample is not representative of all features it is at least indicative and, in view of the consistency of the patterns observed, it would be negligent to argue that the results and conclusion are incorrect in either direction or magnitude. The shortfalls undoubtedly exist and they are not small.

For future work, it would be reckless to assume that the results of this investigation are, by themselves, an adequate basis for designing and planning the required efforts. Basically, the need that has been identified is for development of attitudes and skills in the industry and such development must involve all levels of management to some degree. Such a committment will require more complete participation and more detailed effort than could possibly be based on this investigation alone and, to be effective, should have continuing participation or multi-level planning by or with the industry. In essence, if industry-wide education is required, a significant industry input to the process will be essential.

In brief, this report can be regarded as a practical test of the status of mine maintenance management if only because it has shown conclusively that a program with major industry participation is required. An outline of such a program is appended (see Appendix C) both to amplify the concept of a participating effort and to demonstrate the scale of the required effort.

10.5 Conclusion

There is little doubt, using the results of the recent survey as a guide, that the management of mine maintenance leaves much to be desired. Not only is maintenance poorly managed, which in many cases is the result of attitude, but there are grave deficiencies in the areas of information and understanding of what can be done to improve management of the function.

The costs of maintenance in the participating companies range between 35%-55% of operating costs and there is some concern among managers for these cost levels. Indications are that many managers would welcome improved, less costly systems. However, litle, if any, basis exists for evaluating existing system or for designing improvements.

In today's mining environment, effective management of maintenance requires fairly sophisticated planning systems with experienced management personnel who have the knowledge and the skill to manage such systems. The survey clearly indicated that the availability of such personnel is limited. Many operations are blessed with a good supply of people who have both the skill and experience with practical maintenance work but there is an obvious shortage of suitably qualified personnel to manage the necessary control systems.

Notwithstanding the above analysis, to develop a rational approach to maintenance management primary consideration must be given to attitude. In fact, a positive attitude to maintenance is perhaps the first step in the attempt to systematize maintenance programs. This attitudinal approach must start at the top level of management since the example set by this level will be reflected throughout the organization.

It was evident during the survey that there is still room for improvement in the area of attitude to maintenance. Some progress has been made, but there are some managers, especially at the executive level, who still believe in the old concept of crisis-oriented maintenance management. This belief supports the retention of irrational, unplanned, inadequate approaches to maintenance management. Today's maintenance function imposes great demands on mining operations and if crisis-oriented management is the norm, not only are high maintenance costs assured, but the function will be unable to meet the demand in the work place.

To escape that state and, at the same time, gain some control of maintenance cost, the industry must first change its attitude and then learn what management and analytical methods are available, how they can be applied, and how they work. In effect, there must be a combination of an attitudinal change and a re-educating process and it must be seen as the responsibility of every level of management.

Finally, it is emphasized that in this analysis, no rigid conclusions are intended. It is not implied that existing systems are failing or that there is no evidence of some degree of success. On the contrary, it is clear only that there are problems in maintenance management and that solutions are necessary and available to effect improvement. Appendix C outlines a proposal for future work.

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APPENDIX A
APPRAISAL QUESTIONNAIRE
FOR THE
MAINTENANCE MANAGEMENT PROGRAM

APPRAISAL QUESTIONNAIRE (CHECK-LIST) (36, 55, 84)
MAINTENANCE MANAGEMENT PROGRAM (MMP)

(A) Top Management (Executive Level)

1. Is there a positive attitude to maintenance?
   Check by asking the following:

   a) Is maintenance considered as subordinate to production?
   b) Is it the "dumping-ground" for problems in the production area?
   c) Is it represented at the decision-making level?
   d) Is an example of the positive attitude set at this level?

2. Are maintenance objectives spelt out in clear, accurate terms?
   Check by asking the following:

   a) Are these objectives in writing?
   b) Are they made available to relevant personnel, especially those in maintenance?

3. Are maintenance policies clearly established?
   Check by asking the following:

   a) Are these in the form of written guidelines?
   b) Are they designed to implement the specific maintenance objectives?
   c) Are they available to maintenance personnel?
   d) Do they cover the following important areas:
      - scope and limit of maintenance?
      - type and level of service expected?
      - authority of maintenance management?
      - budget and financial controls?
      - reporting procedures?
      - maintenance personnel?
      - maintenance procedures?

4. Is there a total "life-cycle" maintenance approach which

includes:

- collecting data on equipment operation and maintenance?
- liasing with equipment manufacturers?

5. Is there an annual maintenance report?

6. Is there a maintenance management manual?

7. Is interest shown by this management level to the performance and problems of maintenance?
   Check by asking the following:

   a) Is the present status of the maintenance managment program known?
   b) Has an appraisal or evaluation been carried out recently?

(B) Middle Management (maintenance superintendent , engineer, supervisors)

Is there an efficient and effective MMP within the organization for controling the maintenance function?
Check by asking the following:

Organization and Administration

1. Is there a responsible organization set up within the maintenance department, with clearly defined lines of authority and established responsibilities for key personnel?

2. Is there a separate group within this organization with specific responsibility for the overall control of the MMP?

3. Are area maintenance workshops properly organized and well equipped to provide the type and level of service required?

4. Are area maintenance workshops stategically located so that response in event of emergency repairs is done as

quickly as possible?

5. Is there a system which allows constant interaction between maintenance and the other departments in the organization?

6. Is the maintenance department providing the production department with the type of support services required by management?

Systems and Procedures

1. Is there a comprehensive, up-to-date equipment list that represents an accurate inventory of all equipment controlled by the maintenance department?

2. Is there a set of forms (paperwork system) that assists in initiating action and collecting control data?

3. Is there a job initiating system that makes mandatory the use of standard work-order form for requesting maintenance work?

4. Is there a designated group oof personnel who are the only ones authorized to request maintenance work?

5. Is there an established jobs priority procedure closely linked to work request system?

6. Is there a time keeping system that details the procedure for assigning times to completed work orders?

7. Is there a materials control system that details the procedures for issuing and charging materials to work orders?

8. Is there a rigid stores control system, providing accurate information on minimum and maximum amounts of all spares, materials and replacement parts?

9. Is an annual budget, subdivided into monthly sections, prepared for the maintenance department?

10. Are accepted labour standards used to assist in work measurement, for both repetitive and nonrepetitive jobs?

11. Are analytical techniques being used to assist in determining inspection and repair frequencies for repetitive jobs and preventive maintenance?

12. Is there a program aimed at determining the best method of overhaul for major pieces of equipment, including tools, spares and manpower requirements?

13. Is there a program aimed at developing standard maintenance practices that can be applied to minor repetitive jobs?

14. Is there a comprehensive training program aimed at upgrading and improvingg the skills of all categories of craftsmen?

15. Are there standard procedure insttuctions that must be followed in the event of critical problems or emergencies?

Maintenance Plan

1. Is there a maintenance plan (strategy) that adequately describes the work, timing, to be done on each equipment?

2. Does it result in a preventive maintenance program and also include corrective maintenance guidelines for critical units?

Planning and Scheduling

1. Is there a planning section within the maintenance department equipped with trained planners and schedulers, where all work orders are analysed, planned and scheduled prior to issue?

2. Is an annual masterplan, broken down into quarterly and monthly sections, prepared for all repetitive and planned maintenance work?

3. Is the master plan frequently reviewed and subsequently

updated, to keep it in line with objectives?

4. Is planning and scheduling done for all large non-repetitive jobs such as shutdowns and overhauls?

5. Is preventive maintenance work planned and scheduled to ensure maximum utilisation of manpower and minimum production interruptions?

6. Are the principles of work measurement, based on labour standards, utilized in the planning and scheduling of maintenance work?

7. Are techniques such as CPM and PERT used to assist in the planning and scheduling of large jobs, overhauls and projects?

Information System

1. Does the information system permit the timely and accurate acquisition of data so as to ensure effective control of the maintenance function?

2. Is enough relevant data collected to allow the preparation of reports on such aspects as:
   a. Labour Performance?
   b. Material Consumption?
   c. Equipment Performance?
   d. Costs
   e. Inventory
   f. Overall Performance?

3. Is enough information collected and stored to assist decision-making in such areas as:
   a. Planned Maintenance?
   b. Budgeting?
   c. Costing?
   d. Manpower?
   e. Inventory?

4. Does the system allow a free flow of relevant information to and from the maintenance department?

5. Is accurate and timely reporting an integral part of the information system?

6. Are reports presented in a suitable format so that they lend themselves to easy analysis and evaluation?

7. Is the information available used for generating various indexes, for comparison with pre-set targets and to facilitate in monitoring the MMP?

(C) Maintenance Administration (front-line supervision-foremen, analysts)

Is the MMP being executed in accordance with its design and purpose? Check by asking the following questions:

Systems and Procedures

1. Are clearly written work-orders submitted prior to the commencement of all jobs?

2. Are work-orders only accepted when they are signed by personnel, delegated with the authority to request maintenance service?

3. Are work-orders correctly routed after the completion of every job?

4. Are standing work-orders prepared for routine and preventive maintenance tasks?

5. Are these orders properly filed to ensure easy access and speedy identification?

6. Are all preventive maintenance tasks carried out by trained craftsmen?

Planning and Scheduling

1. Is planned maintenance carried out in accordance with the master plan?

2. Are weekly plans prepared in line with the master plan?

3. Are plans updated frequently - weekly or daily?

4. Is daily work planned in advance to minimize lost time?

5. Are jobs scheduled in accordance with the prescribed

priority system?

6. Are routine jobs done on schedule and not delayed by large-job preferential treatment?

7. Are the stores well managed to prevent unnecessary hindrance to planning and scheduling?

8. Are labour standards observed to facilitate planning and sheduling?

9. Are jobs completed on time, in line with dates planned?

Information System

1. Is there adequate liason with production counterparts?

2. Are frequent inter-departmental meetings held at least weekly?

3. Are the reports submitted based on facts?

Human Element

1. Is work generally carried out in clean safe surroundings?

2. Is safety wear provided and worn by all workers?

3. Is on-the-job training encouraged in the department?

4. Are lateness and absenteeism discouraged and reported to the proper authority?

5. Is the level of supervision adequate?

APPENDIX B
TECHNICAL INFORMATION
FOR
WEIBULL ANALYSIS AND GLASSER'S GRAPH

(TABLES B1 - B3, FIGURES B1 - B3)

Table B1 **Median Ranks for the Determination of F(t) for Ungrouped Failure Data Sample Size (N) < 20**

SAMPLE SIZE = n																				RANK ORDER NUMBER
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	
50.0	29.3	20.7	16.0	13.0	11.0	9.5	8.3	7.5	6.8	6.2	5.7	5.2	4.9	4.6	4.3	4.0	3.8	3.6	3.5	1
	70.8	50.0	38.7	31.5	26.6	23.0	20.3	18.1	16.4	14.9	13.7	12.7	11.8	11.1	10.4	9.8	9.3	8.8	8.4	2
		79.4	61.4	50.0	42.2	36.5	32.2	28.8	26.0	23.7	21.8	20.2	18.8	17.6	16.5	15.5	14.7	13.9	13.3	3
			84.1	68.8	57.9	50.0	44.1	39.4	35.6	32.5	29.9	27.6	25.7	24.1	22.6	21.3	20.1	19.1	18.2	4
				87.1	73.5	63.6	56.0	50.0	45.2	41.3	37.9	35.1	32.7	30.6	28.7	27.0	25.6	24.3	23.1	5
					89.1	77.1	67.9	60.7	54.9	50.0	46.0	42.6	39.6	37.0	34.8	32.8	31.0	29.4	28.0	6
						90.6	79.8	71.3	64.5	58.8	54.1	50.0	46.6	43.5	40.9	38.5	36.5	34.6	32.9	7
							91.7	82.0	74.1	67.6	62.2	57.5	53.5	50.0	47.0	44.3	41.9	39.7	37.8	8
								92.6	83.7	76.4	70.2	65.0	60.5	56.5	53.1	50.0	47.3	44.9	42.7	9
									93.3	85.2	78.3	72.4	67.4	63.0	59.2	55.8	52.8	50.0	47.6	10
										93.9	86.4	79.9	74.4	69.5	65.3	61.5	58.2	55.2	52.5	11
											94.4	87.4	81.3	76.0	71.4	67.3	63.6	60.4	57.4	12
												94.9	88.3	82.5	77.5	73.0	69.1	65.6	62.3	13
													95.2	89.0	83.6	78.8	74.5	70.7	67.2	14
														95.5	89.7	84.5	80.0	75.8	72.1	15
															95.8	90.3	85.4	81.0	77.0	16
																96.0	90.8	86.1	81.9	17
																	96.3	91.3	86.8	18
																		96.5	91.7	19
																			96.6	20

MEDIAN RANKS (PER CENT)

Source: Same as Figure B1

Table B2 Determination of F(t) for Grouped, Censored Failure Data (50)

When censoring takes place then the value of F (t) which is required for Weibull plotting of the failure data is obtained via the cumulative failure rate as illustrated in the following table:

Class, weeks	F	C	S	$\frac{S_{t+\delta t}+S_{t-\delta t}}{2}$	Instantaneous failure rate		$F(t)=1-e^{-\Sigma r(t)}$
					Observed r(t)	Cumulative	
0 < 1	9	5	89	82.0	0.110	0.110	0.104
1 < 2	16	1	75	66.5	0.241	0.351	0.296
2 < 3	9	2	58	52.5	0.171	0.522	0.407
3 < 4	7	2	47	42.5	0.165	0.687	0.497
4 < 5	2	5	38	34.5	0.058	0.745	0.525
5 < 6	2	12	31	24.0	0.083	0.828	0.563
6 < 7	3		17	15.5	0.194	1.022	0.640
7 < 8	2	1	14	12.5	0.160	1.182	0.693
8 < 9	2		11	10.0	0.200	1.382	0.749
9 < 10		2	9	8.0			
10 < 11			7	7.0			
11 < 12	1	1	7	6.0	0.167	1.549	0.788
12 < 13			5	5.0			
13 < 14	1	1	5	4.0	0.250	1.799	0.835
14 < 15	1	2	5	1.5	0.667	2.466	0.915
	$\Sigma=55$	$\Sigma=34$					
	$\Sigma\Sigma=89$						

F = Frequency of Failure

C = Censoring Frequency

S = Survivors at commencement of interval

$r(t) = F/\ (S_{t+\delta t}+S_{t-\delta t})/2$

Table B3 Graphical Solution of the Block and Age-based Preventive Replacement Policies (Developed by G.J. Glasser in his paper "Planned Replacement: Some Theory and its Application", Journal of Quality Technology, Vol. 1, No. 2, April 1969.

a) Requirements prior to using the graphs (Figures B2 and B3) are that:

1. the failure distribution of an item/component can be adequately described by a Weibull distribution - with its mean (μ) and standard deviation (σ) known.
2. the total costs associated with a failure replacement (C_f) and a preventive replacement (C_p) are known.
3. the objective is to minimize total cost/unit time.

b) Solution procedure for either graph (apply in conjunction with Figures B2, B3)

Step 1. Determine cost ratio $= \frac{C_f}{C_p}$

Step 2. Determine ratio $= \frac{\sigma}{\mu}$

Step 3. Read off the graph the value of z corresponding to the intersection of a horizontal line from κ and a vertical line from ν

Step 4. The optimal preventive replacement time, t_p, is obtained from:

$$t_p = \mu + z\sigma$$

Step 5. The value of ρ at the intersection of the appropriate κ and ν values gives the cost of the optimal policy as a decimal fraction of the cost of a "replace only on failure" policy.

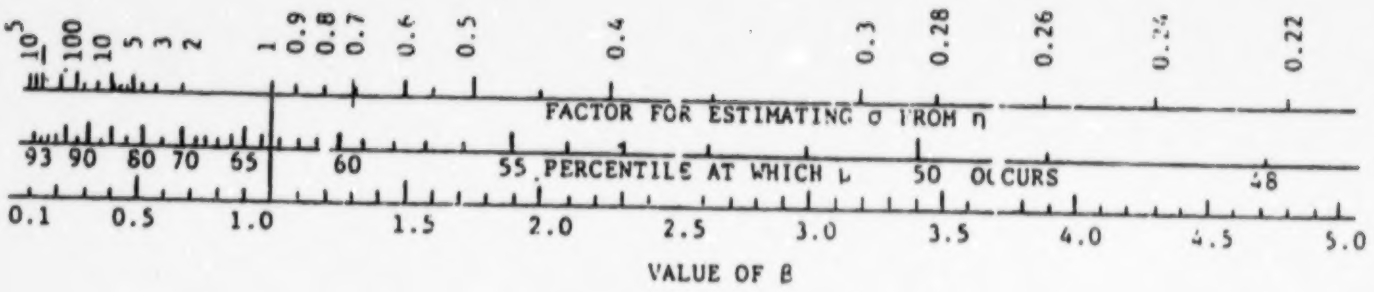


FIGURE B1: NOMOGRAPH OF THE RELATIONSHIP OF β, μ and σ. for the determination of σ

Source: Team, Vol. 3, No. 1, 1976 -- An Introduction to Weibull distribution statistics

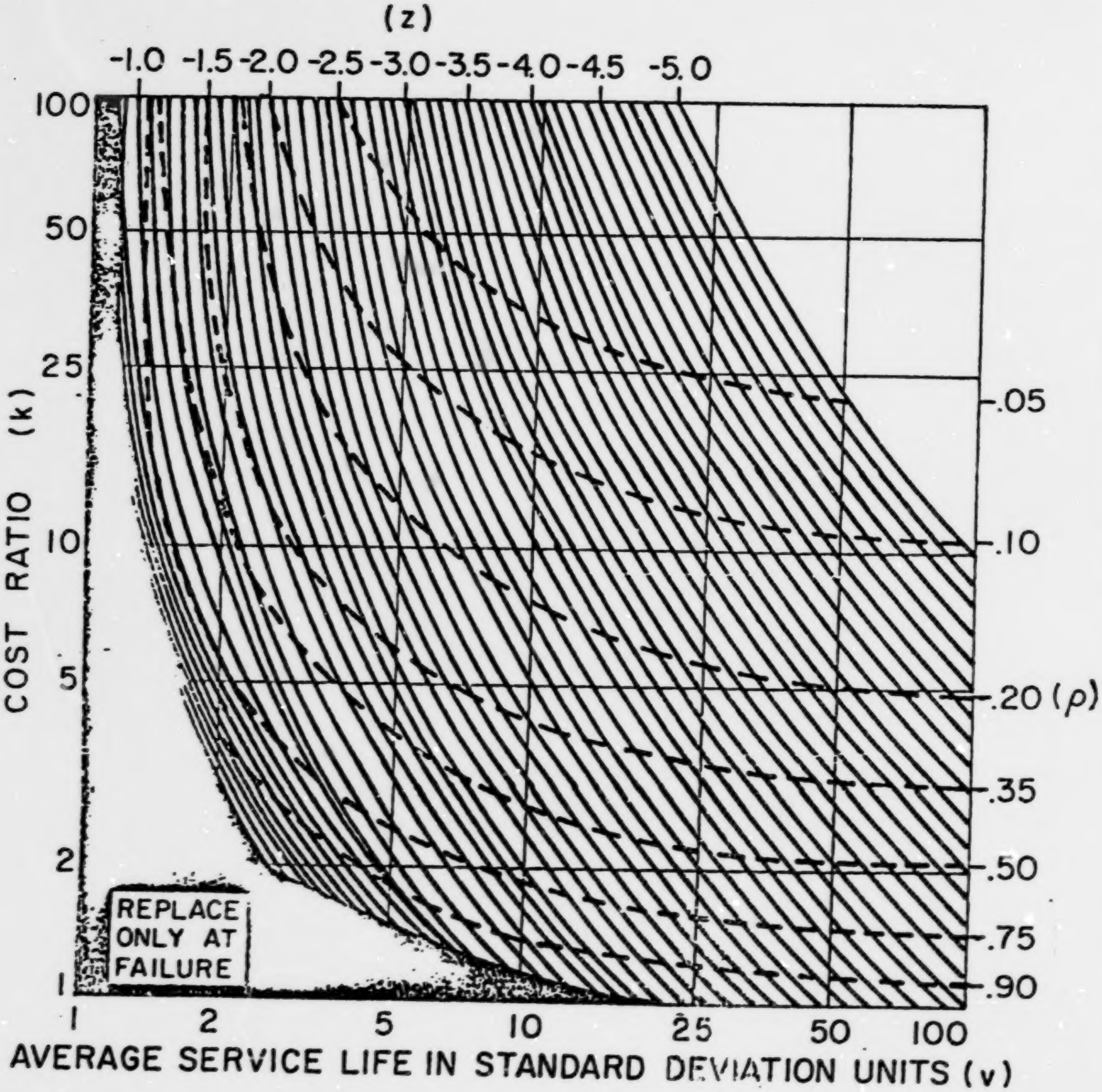


Fig. B2 Glasser's graph for block replacement
(Journal of quality technology, V1, N2, April, 1969)

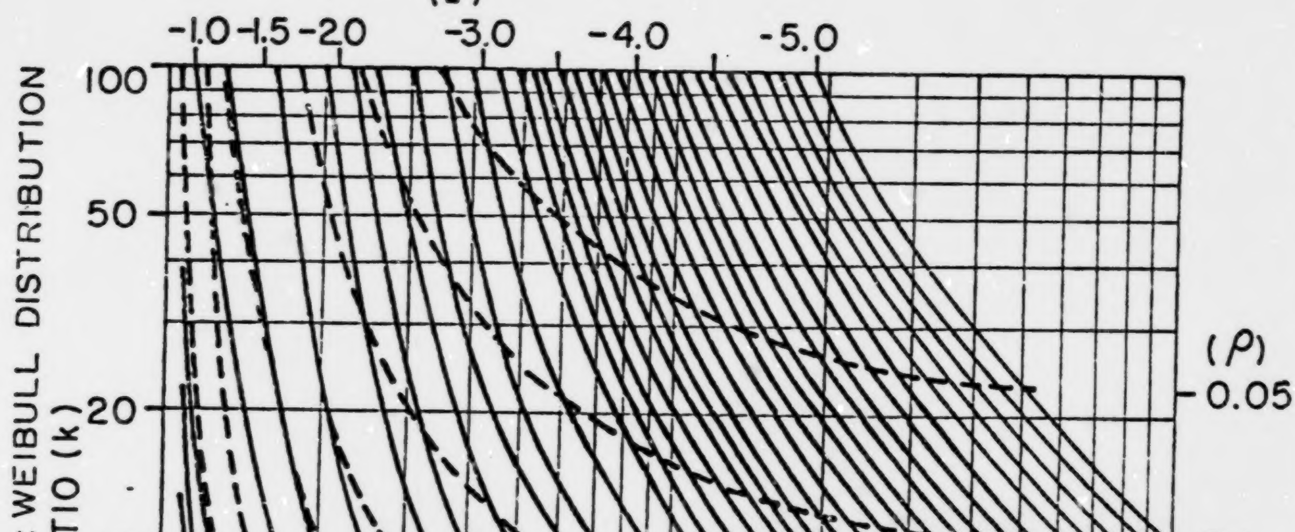


Fig. B3 Glasser's graph for age-based replacement (50) (Journal of quality technology, V1, N2, April, 1969)

APPENDIX C
PROPOSAL FOR FUTURE WORK

OUTLINE OF A PROPOSAL FOR FUTURE WORK

1) The Problem

This investigation has examined the state of mine maintenance management in Canada with special attention to

- the technology, organization and methods available
- executive level management
- mine general management
- line management and supervision.

The results of the investigation can be summarized as follows:

1) the technology and system that can be used in mine applications exist; there is no need for a system research and development program.

2) shortfalls in one or more of management attitudes, and systems exist in most of the organizations visited. That is, for one property there may be no sensitivity to a management problem at the executive level, the property general manager may be totally competent and appreciative of the problem but his line staff may be unprepared to implement a system. Moreover, there is no management education program available at present and the pool of prepared line staff is small - even non existent.

It is clear that the basic pattern is one of developing both attitudes and skills in mine maintenance at all levels and especially of doing so without an established teaching system for the area. Fundamentally, it represents an industry-wide need for, but lack of, a teaching/training capability.

The Options

Four approaches can be taken to finding or developing an approach to this problem as follows:

- Use CANMET staff or organization in which to organize a teaching/training program'
- Use consultants now offering maintenance manage-

ment services as the core of a teaching/training program
- Use a university as the location for a teaching/training system
- Organize a new teaching/training agency that is specifically qualified for this project.

Of these, the first is not recommended because CANMET has no basis in current staff interests or orientation for mounting what would be an entirely new effort. The second is not advocated due to the improbability of either assembling a group of consultants into a cohesive effective group or of selecting one to undertake the project. The university approach is not recommended either because of its grave lack of orientation to the highly practical and pragmatic needs of the field and because the required program should be an on-going one, not one that could be complicated by the conventional academic schedule.

A distinct advantage of a new agency would be the opportunity to design it to take advantage of existing resources - constituting staff from universities, CANMET, consultants and the industry - on a continuing independent basis. Similarly, a new agency need not require capital committments; also, it could be established in a commercial location and developed as the needs and detailed requirements are established. In this last aspect, it is clear from this investigation that extensive participation by the industry in the design and development of the agency will be in order.

To finance a new agency it would be helpful if total sponsorship were possible, say through the Mining Association of Canada, or through provincial associations. However, for illustrative purposes it can be assumed that the development will proceed as an independent self-supporting, but endorsed agency and that the cooperation of the industry will be available.

It is an agency of this sort for which the following approach is proposed.

Procedure

Basically, it is proposed that a three-stage program of development be adopted by a new agency for the purpose of developing management skills and methods for mine maintenance management. The program will be based on the following premises:

1) that the attitude of executive level management and maintenance management of a company should be tested and confirmed to ensure that the need interpreted in this report exists, that the costs will be justified, and that a program to solve the problem will require at least 5 years for results to be definable.

2) that the organization and procedures used at different properties must be accommodated as much as possible in the proposed teaching/training program

3) that the end point of the first two premises will be the development of a teaching/training support for line supervisors and managers at least; also that this new system will not be a new consulting agency

4) that the new agency will provide a teaching/training service at fee levels to establish it as an independent venture

Under these conditions, a three stage program is proposed as follows:

1) Executive Identification Stage
2) Manager Evaluation/Design Stage
3) Staff Instructional Stage - the operating system.

The essential features of each stage follow.

1) Executive Identification Stage

Content: the Presidents of Canadian mining companies will be invited to meet in a one-day symposium in which the dominant features of this investigation will be presented and evaluated. The goal will be to obtain specific company commitments to following up the conclusions and recommendation of this investigation with appropriate action committments including

a) Identification of a positive Maintenance Policy on a corporate basis
b) Identification of the aim of developing a significant educational program in maintenance

Decision: if such identification is not established in this meeting to the extent that stage two is clearly justified, this proposal can be abandoned at the end of Stage 1. If such identification is achieved, it is assumed that stage 2 will be undertaken.

Location: Toronto, Ontario

Duration: 1 day

Attendees: Presidents or appropriate vice presidents

Organizers: The principals of this investigation

Budget: $10,000

Finance: Projected for 20 registrants at $500 fee

Schedule: Preferably October 1983.

2) Manager Evaluation/Design Stage

Content: An intense symposium/seminar will be organized in which the major areas of this investigation, adjusted as determined in the Executive Identification Stage, will be presented. For this presentation, experts in appropriate selected areas will participate so as to ensure maximum preparation and analysis of all areas. The goal will be the determination of subject areas and approaches for a teaching/training system to be organized as the third stage. Specifically, the stage will seek to

a) Determine the preferred format and contents of a teaching/training program and,

b) Confirm that the program will be useful and used by the participating companies at least through a reasonable trial period.

In essence, if stage 1 determines that a program should be designed, stage 2 will determine from the participating companies the content of the programs and make commitments to paticipate to some extent.

Decision: If it is determined in stage 2 that a practical program cannot be prepared, this proposal can be abandoned at this point. If support is inconclusive, a decision to proceed can be taken by the new agency on the basis that appears appropriate at the time with no further financial endorsement assumed.

Location: Donald Gordon Centre, Kingston, Ontario, or a similar conference facility

Duration: two to three days

Attendees: General managers of mining operations

Budget: $20,000

Finance: Projected for 30 registrants at $700 fee

Schedule: Preferably January 1984.

3) Staff Instructional Stage - The Operating System

Content: a series of one to three week courses presenting essential elements in management of mine maintenance systems focusing on such subjects, separately or in combination as,

a) Organizing of the maintenance department
b) Paperwork system, work order, etc.
c) Maintenance strategies
d) Techniques in planning and scheduling
e) Information systems

f) Computer seleting and operating data systems
g) Statistical methods for maintenance management
h) Implementing and monitoring the maintenance program

Each of these courses will provide a brief overview of the requirements and goals of mine maintenance system followed by an intense pragmatic treatment of the subject area(s) of the course. Each attendee should, thereby, receive an intense practical preparation in at least one area for which he will have operating management responsibility. For each property the number of staff taking courses will be determined by the type of system, size of the operation, preparation of staff and so on in accord with the property manager's plan for his property.

Location: Donald Gordon Centre, Kingston, Ontario, or similar conference facilities to suit the industry

Duration: One to three weeks per course

Attendees: Line managers, engineers and supervisors as appropriate for individual properties

Budget: $10,000 per instructional week

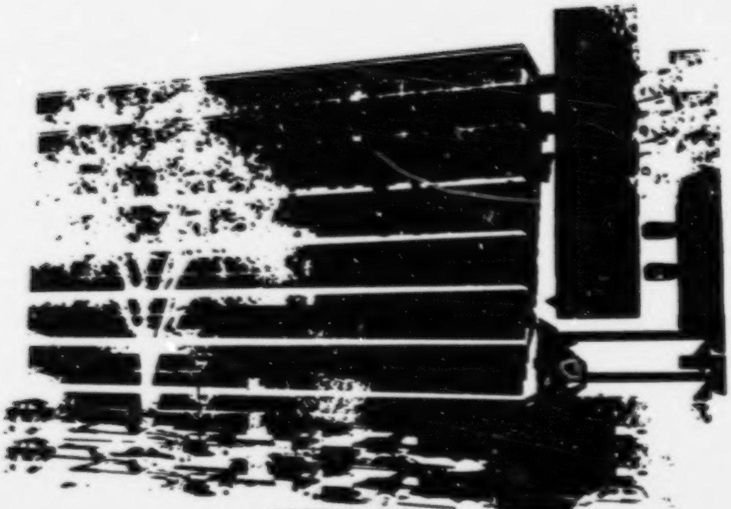
Finance: Projected for 20 registrants/week @ $600 fee per week

Schedule: Beginning spring 1984 and continuing to satisfy the demand.

Summary

This investigation has established that there is a general lack of preparation for management by available desirable technique of mine maintenance operations. Moreover, the shortfall of qualified personnel is too great to expect the industry to develop the improved maintenance systems that seem possible without establishing a new teaching/training capability.

This proposal illustrates a method for developing such a teaching/trailing facility that will be uniquely and specifically oriented to the industry. The approach is expected to be independent, self-supporting and subject to termination if its prospects fail to satisfy the industry.



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